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MAKING CYLINDERS AND SLUMP TEST IN STUDIES OF MIXING TIME

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THE EFFECT OF THE LENGTH OF THE MIXING PERIOD ON THE QUALITY OF THE CONCRETE MIXED IN STANDARD PAVERS

BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS[1]

Reported by J. L. HARRISON, Highway Engineer

A RECENT survey of the specifications governing the mixing of concrete for highway pavement indicates that 33 States require a one-minute mix, 6 a one and one-fourth minute mix, and 9 a one and one-half minute mix. Specifications are constantly being changed and a summary of this kind may be in error before it is published. This is mentioned only to indicate the lack of standardization now prevailing.

It may be admitted at once that absolute standardization of highway practice in all of its elements is neither practicable nor desirable. Conditions vary from place to place and as a general rule are not so uniform over an area as large as the United States as to justify the adoption of uniform requirements. But in respect to the mixing time of concrete a somewhat different condition prevails. The same kinds of mixers are used from one coast to the other and their mixing action is not subject to regional variation. Cement is a relatively uniform product, and water outstandingly so. Aggregates differ considerably and are used in different proportions, but there is very little reason to suppose that the variations permitted have any important effect on the physical processes involved. These and other minor considerations suggest that the commonly accepted reason for varying specified practices from region to region—namely, that variations in the controlling conditions compel these variations—does not properly apply here.

EFFECT OF MIXING TIME UPON QUALITY OF CONCRETE ONLY FIRST PHASE OF INVESTIGATION

The required mixing period establishes a limit on the amount of concrete which can be placed during any given period of time. Previous studies have shown that with a mixing period of one and one-half minutes, only 34 batches can be placed per hour, which is 340 batches per 10-hour day; or, for a standard 18-foot Maricopa section, about 910 lineal feet of pavement if a 6-bag batch (1:2:3½ mix) is used.[2] If a one-minute mixing period is specified, 48 batches can be placed per hour which, under the same conditions, is about 1,290 lineal feet. If operating costs (labor, equipment operation, depreciation, etc.) run about $400 per working day—and, while these costs differ somewhat from place to place and from job to job, this figure is as fair as any, the labor and equipment costs, overhead, etc., incident to laying concrete pavement can not in the first case be cut much under 22 cents a square yard, while in the second case, they can be forced down to about 15 cents—a saving which runs into large figures when the amount of pavement laid annually under a long-time mixing requirement is considered.

The ultimate objective of the investigation of which this paper is a partial report is the more accurate determination of the effect of variation in the mixing time upon the cost of concrete production. At the outset, however, it has been recognized that requirements of strength and uniformity probably impose a definite limit below which it is not safe to reduce the mixing time in order to obtain further reduction of cost. Hence, as a first phase of the investigation, a study has been made of the effect of several mixing periods upon the quality of the resulting concrete product.

In a general way research has indicated that there is a difference between the strength of concrete mixed for very short periods and that mixed a long time. This investigation is not designed to attack this conclusion and does not set it aside. Rather, a situation is faced in which at the moment our interest is neither in the effect of very short-time mixing, because modern pavers can not be served fast enough to make any real use of a mixing period shorter than 45 seconds, nor in mixing periods beyond about 90 seconds, because these already have been generally abandoned as obviously too expensive to justify whatever benefit to quality may result from their use.

But, while the question directly involved is as to the effect of mixing periods of from 45 seconds to 90 seconds on quality, it may be well to repeat that the controlling purpose of the investigation has been to determine whether the cost of concrete pavements can be reduced through modifications in the prevailing specifications as to the time concrete must be mixed. In other words, this is not to be considered as a research on the general relationship existing between mixing time and strength. No effort has been made to extend the scope of the investigation much beyond the rather narrow range of time limits which may be applicable in the paving field, or to examine ranges in water content not appropriately used in this field.

On account of the deliberately limited scope of the investigation this report is not to be accepted as justifying a shortened mixing period when types or sizes of mixers other than the standard 21E and 27E pavers are used; nor do the conclusions which are drawn apply to concrete of other mixes (including water) than those in general use in highway work. The writer does not know that the results do not apply to these other conditions. These simply have not been examined, and conclusions can not be drawn.

THE EFFECT OF MIXING TIME ON PRODUCTION

Under current specifications, as commonly enforced, the minimum time required per batch for various mixing periods and the number of batches that could be produced in an hour if the rates shown could be maintained without interruption or loss of time, are given in Table 1. To produce concrete at the rates

[1] This study was made possible through the hearty cooperation of the several State highway departments and the contractors doing the construction. Among the field men of the bureau engaged on the work were A. C. Taylor, C. F. Rogers, R. E. Tribou, W. A. Blanchette, T. E. Kesting, F. R. Hall, F. W. Pierce, jr., and T. C. Thee.

[2] HARRISON, J. L. EFFICIENCY IN CONCRETE ROAD CONSTRUCTION, Public Roads, vol. 6, Nos. 9, 10, 11, 12, and vol. 7, No. 1.

shown for the several mixing periods it must be assumed that there is no loss of time between batches, and that the mixer is operated continuously for the full length of the working day. In practice, such full production is seldom if ever attained; and production averaging 70 per cent of the theoretical maximum would ordinarily be considered quite satisfactory.

TABLE 1.—*Minimum time required per batch for various mixing periods*

Specified mixing time	1½ minutes	1¼ minutes	1 minute	¾ minute
	Seconds	*Seconds*	*Seconds*	*Seconds*
To raise skip	10	10	10	10
Charging lag (to permit all material to run into drum)	5	5	5	5
Actual mixing time, all other operations fully overlapped	90	75	60	45
Total time required	105	90	75	60
Batches to be had per hour	34	40	48	60

Whether the mixing period be one and one-half minutes or three-fourths minute, therefore, it must be recognized at the outset that the full production corresponding to the two periods can not be hoped for. From a practical standpoint the important questions are whether the reduction in the mixing period can be utilized to increase production and how fully it can be utilized. These are questions which are being studied in another phase of the current investigation.

It must be admitted that it is much easier to organize a job to serve the mixer fully for a one and one-half minute mix than it is to serve a three-fourths minute mix. Still, records collected by the bureau's representatives on 19 jobs in a State where a one and one-fourth minute mix is required, show an average hourly output of only 22 batches during periods when work is under way, while an average hourly production of over 40 batches is rather common in another section where a one-minute mix is permitted, and averages of over 45 batches per hour are known to have been sustained over considerable periods of time. This suggests that there is a tendency for the actual rate of production to fall below the maximum permissible rate whether the latter be relatively low or high, and that the actual rate rises as the permissible rate is raised. If this be true, then the questions that remain to be determined are (1) to what minimum period is it possible to reduce the mixing time and economically utilize the time saved to increase production, and (2) what is the minimum period of mixing that will produce a concrete of satisfactory strength and uniformity. The first of the questions is being attacked in the other phase of the investigation, previously mentioned; the second is the subject of this report.

STUDIES COVER A WIDE SCOPE

In collecting the data reported in this article studies have been made on projects in Michigan, Missouri, Kansas, Tennessee, Texas, South Carolina, and Oklahoma. Over 2,000 cylinders have been broken, records on some 1,500 of which are reported in this article, together with a considerable number of beams and cores.

All of this work has been done in cooperation with the State highway departments of the States where studies were made and in harmony with the technical suggestions of the State engineers. Numerous contractors have cheerfully furnished concrete for the cylinders and the beams without charge, and often have contributed labor and in other ways assisted in making this study a success.

The prevailing opinion as to the importance of mixing time is based almost entirely on determinations of compressive strength which is the most generally accepted criterion of quality, and it has been freely used in this series of studies. To have done otherwise would have raised a reasonable question as to what the results mean in terms known and accepted by the industry generally.

The use of cores taken from the finished work has some advantages over the use of cylinders as a means of determining what strength is actually being obtained. Where it has been possible to do so, cores have been taken as a check on the results obtained from the cylinders.

The modulus of rupture has recently come into some use as a means of studying quality. While it is by no means well established as such, or as well standardized as the compression test, it has been deemed wise to use both cylinders and beams on a few of the jobs where studies were conducted, the purpose being to learn whether transverse bending tests would show results clearly different from those obtained by using standard compression tests.

The general plan of this study follows the usual practice in studies of this sort, in that it is a series of determinations of compressive strength of molded cylinders, but the compressive-strength data which has been secured has been amplified and confirmed by tests on cores and on beams as often as field conditions permitted. It should, therefore, be somewhat more conclusive than a study based on only one of these methods of determining quality.

PROCEDURE IN FIELD STUDIES DESCRIBED

The details of these studies have varied a little from job to job, these variations having been dictated in part by the information gathered as a result of the earlier tests, and in part by the preferences of the State authorities whose cooperation was secured. On the first projects studied, cylinders were taken for 30-second, 45-second, 60-second, 90-second, 120-second and 180-second mixes. On later jobs the work was limited to 45-second, 60-second, and 90-second mixes. On occasional jobs a 75-second mix was used instead of or in addition to a 90-second mix.

As a general rule the full batch was dumped on the subgrade at the end of the mixing period, material for one cylinder and for a slump test being taken from about the center of the batch. In a few instances more than one cylinder was taken from the batch. Generally no objection has been raised to the use of a limited number of short-time batches in the finished road but in a few cases the State authorities preferred not to do this, and in these cases the effect of short-time mixing (30 and 45 seconds) was determined by discharging only a portion of the batch from which a fair sample was selected. On two jobs (Michigan Federal-aid projects 187A and 187B) a full series of cylinders (one-half minute to three minutes) was taken each day from a single batch, a sample of the concrete being discharged into a galvanized-iron bucket after each mixing period in the series, the balance of the material being retained

in the drum and discharged after the three-minute sample had been taken. While this sort of sampling is hardly to be recommended, no significant variations in results appear to have resulted from it or from any of the other differences in the manner of taking samples.

Cylinders were prepared as required by the A. S. T. M. standards and, except as otherwise noted, were cured in moist earth until shipped to the laboratory. They were broken, as were all cores, under the practices prevailing in the laboratories to which they were sent, except in the case of work done in Missouri, where, through the courtesy of authorities of the University of Missouri, cylinders were broken in the university laboratory by one of the bureau's engineers. All test cylinders and beams were broken at 28 days except in a few instances where they were broken at 27 or 29 days.

Slump tests were made regularly as were moisture determinations and analyses of the aggregates used. A record was kept of the quality of the cement. The number of revolutions per minute at which the mixer drum was operated was determined at frequent intervals. The operation of the water tank was checked from time to time and the accuracy of the water gauges checked as often as conditions required.

ORGANIZATION ON ONE OF THE JOBS STUDIED. PRACTICALLY ALL OF THE JOBS STUDIED WERE WELL ORGANIZED AND EQUIPPED

TABLE 2.—*Data on cylinders taken on Federal-aid project 136X in Kaufman County, Tex.*

[Mix 1:2:3.4; gravel coarse aggregate; Koehring mixer in good condition]

30-second mix			45-second mix			60-second mix			90-second mix			120-second mix			180-second mix		
Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
1	0.67	5,470	1¼	0.69	5,620	1⅛	0.66	5,880	2¼	0.68	5,660	1¾	0.66	5,480	1¼	0.71	6,410
	.71	5,720	1¼	.66	6,080	1¼	.66	6,980	2¼	.68	5,520	2	.63	6,125	1¼	.71	6,460
1¼	.63	5,890	1¼	.69	6,670	1	.67	5,310	2	.65	6,360	2	.63	6,550	2¼	.68	5,570
1¼	.63	6,220	2¼	.74	6,430		.67	5,970	2	.65	5,960	2¼	.68	4,015	2¼	.68	6,180
2	.62	5,000	4¼	.77	5,470	2	.67	5,520	2	.66	6,050	2¼	.68	4,820	2¼	.68	
1	.67	5,470	[1] 1¼	.55	5,775	2	.67	4,750	[1] 1½	.58	6,220	[1] 1½	.57	4,870	2¾	.68	
1	.71	5,720	[1] 1¼	.55	6,575	2¼	.68	6,450	[1] 1½	.58	6,310	[1] 1½	.57	4,500	2	.66	6,930
			[1] 1¼	.55	6,110	2¼	.67	6,280	[1] 1½	.58	6,565	[1] 1½	.57	5,670	2	.66	6,230
			[1] 1¼	.55	6,820	1½	.66	6,670	[1] 1½	.58	6,420	[1] 1½	.57	4,485	2	.66	6,870
						1½	.66	6,270									
						2	.66	6,110									
						4¼	.71	5,870									
						2	.67	5,770									
						2	.63	5,980									
						[1] 1½	.57	5,630									
						[1] 1½	.57	5,230									
						[1] 1½	.57	5,475									
						[1] 1½	.57	5,470									
Av. 1.25	.664	5,641	1.25	.639	6,172	1.54	.545	5,867	1.39	.626	6,118	1.36	.618	5,168	1.94	.68	6,378

[1] Water-cement ratio controlled at low point for test purposes.

DATA SECURED INDICATES STRENGTH NOT INCREASED BY LONGER MIXING PERIODS

The tables which follow, together with the comments on them, give most of the results obtained during the study and discuss the manner in which these tables bear on the question of appropriate mixing time.

MAKING SLUMP TEST AND CASTING BEAMS ON OKLAHOMA FEDERAL-AID PROJECT 148E

The cylinders and the cores recorded in Tables 2 and 3 were taken from Texas Federal-aid project 136, Kaufman County, Tex., which was constructed under the direct supervision of S. J. Treadaway, county engineer, through whose courteous assistance this work was made possible. The high strength as well as the unusual uniformity of the results deserve special note. Except as otherwise noted, the cylinders taken on this job represent the normal run of concrete, no special precautions having been taken to insure a more uniform water content than was in ordinary use. Each cylinder represents a separate batch of concrete. Table 3 gives the strength of a group of cores cut from this pavement. The crushing strength of these cores entirely confirms the high quality of this concrete. The tendency of long-time mixing to slightly increase the slump should be noted.

Table 4 gives the breaking strengths of a number of cylinders taken by the regular inspector, all of which were mixed one minute. These, too, confirm the high quality of this work.

There is little to be said in explanation of the results shown by this series of cylinders. The average strength of cylinders mixed one-half minute is a little less than 10 per cent lower than the strength of those mixed three-fourths minute. The average strength of the cylinders taken from batches mixed three-fourths minute is higher than the average strength of any other group except those mixed three minutes. However, there is no significance in these differences as the three-minute cylinders average only about 3 per cent stronger than the 45-second cylinders, a difference so much less than the margin of error which must be allowed in work of this kind that it must be ignored unless it can be shown to persist through a long series of tests.

The cores taken from the 45-second batches were stronger than those taken from the three-minute

TABLE 3.—*Results of compressive-strength tests made on cores taken from Federal-aid project 136 in Kaufman County, Tex.—Cores taken at ages varying from 28 to 55 days and tested within a few days after being drilled*

45-second mix	60-second mix	90-second mix	120-second mix	180-second mix
Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
5,670	[1] 4,740	7,280	6,320	6,210
6,080	6,250	5,690	5,800	5,550
6,240	[1] 3,790	----------	6,590	----------
----------	6,160	----------	----------	----------
----------	6,090	----------	----------	----------
----------	5,900	----------	----------	----------
----------	5,860	----------	----------	----------
----------	5,800	----------	----------	----------
----------	5,700	----------	----------	----------
----------	5,430	----------	----------	----------
----------	5,700	----------	----------	----------
Av. 5997	5,877	6,485	6,237	5,880

[1] Probably damaged; omitted from average.

TABLE 4.—*Compressive strengths of cylinders taken by regular inspector on Federal-aid project 136 in Kaufman County, Tex.*

[All batches were mixed 1 minute]

(In pounds per square inch)

5,830	5,450	6,270	5,530
5,840	5,750	6,680	5,950
5,490	5,620	6,440	5,610
5,470	6,300	6,810	5,800
5,700	6,750	6,230	5,600
5,320	6,560	6,630	6,150
5,300	6,000	6,280	5,845
5,900	6,860	5,480	6,140
5,960	5,730	6,450	6,500
6,210	4,990	6,150	6,540
6,330	4,870	5,750	5,620
6,530	5,140	6,500	6,935
6,020	6,360	5,830	
5,540	6,720	5,390	Av. 5,999
6,630	6,690	4,970	

batches. As in the case of the cylinders, this difference is due to the wide difference between the maximum and minimum strength that is usually found in a series of cylinders or cores. A few more than the ordinary proportion of good or bad specimens will yield an average that is out of line. Taking this fact into consideration it does not appear that there is any significant difference in the strengths obtained under the various mixing times from 45 seconds up, either as indicated by the cylinders or by the cores.

Another matter to be noted is that the uniformity of the results has not been increased by the longer mixing. The maximum variation in the strength of 45-second cylinders is about 1,350 pounds. The maximum variation in the strength of the three-minute cylinders is 1,360 pounds. This condition persists throughout this study.

The matter of most importance is that concrete of the highest quality—averaging more than twice the strength commonly called for in specifications governing this work—was obtained with a mixing time of 45 seconds and that concrete having a strength of 5,600 pounds and with a uniformity in test results equal to that secured by mixing the batch three minutes was mixed in 30 seconds. Time in this work was read from the instant the timer was set with no allowance for lag in getting materials into the drum. The mixing time, as used here, is, therefore, about two seconds less than the time required as specifications are commonly interpreted. This series of cylinders and cores suggests that mixing in excess of three-fourths minute, was not a factor in obtaining either strength or uniformity in test results and that the strength, at least as far as it can be determined by standard tests, depended on other factors.

NO DIFFERENCE IN RESULTS SECURED WITH STANDARD 21E AND 27E MIXERS

Table 5 gives the strength of a few cylinders obtained from a job in Bowie County, Tex., which was constructed under the immediate supervision of D. K. Caldwell, consulting engineer.

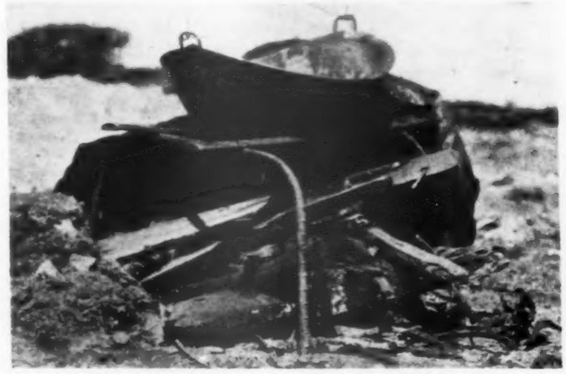
TABLE 5.—*Results of compression tests on cylinders from Texas Federal-aid project 415C in Bowie County, all batches mixed 1 minute*

[Mix 1:2:3½; gravel coarse aggregate; Koehring mixer in good condition and new Ransome mixer]

Slump	Compressive strength—Koehring mixer	Compressive strength—Ransome mixer	Slump	Compressive strength—Koehring mixer	Compressive strength—Ransome mixer
Inches	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
1	6,370	----------	1¾	5,580	----------
1	6,380	----------	2	----------	7,000
1¼	6,790	6,450	2	----------	7,620
1¾	6,000	6,060	2	----------	5,875
1¾	----------	5,510	3	[1] 4,720	6,490
1¾	----------	4,750	3	[1] 4,790	----------
1½	----------	5,440			
1½	----------	5,820	Average	6,188	6,101
1¾	6,010	----------			

[1] Not included in average because of high water content.

6-bag mixers used on Texas project 415C. In this case the average strength of concrete mixed 45 seconds was higher than that mixed a longer or a shorter period. There was some difference in the materials used on this and the preceding job but the cement tested as high on this job as on the other. The water content as determined in the field was low. It will also be noted



DRYING OUT A BATCH OF FRESH CONCRETE TO CHECK PROPORTIONS AND WATER-CEMENT RATIO

TABLE 6.—*Data on cylinders taken on Federal-aid project 479 in Bowie County, Tex.*

[Mix 1:2:3½; gravel coarse aggregate; Koehring and Ransome mixers in good condition]

30-second mix			45-second mix			60-second mix			90-second mix			120-second mix		
Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
1½	0.414	3,420	1¾	0.649	4,150	1½	0.402	4,830	2	0.560	4,790	2	0.532	3,360
3	.469	3,280	1½	.649	4,380	1½	.425	4,950	3½	.618	3,920	¾	.534	4,750
¼	.462	4,480	2	.677	4,400	1	.369	4,680	2½	.591	4,590	1¾	.503	3,440
1	.498	4,240	1¾	.605	4,510	1¾	.515	3,440	2¾	.612	4,100	1	.459	4,850
1¼	.478	4,920	1¼	.617	4,330	2	.500	3,750	¾	.537	4,920	2	.557	3,630
1¼	.484	5,200	1½	.537	4,800	1¾	.468	3,650	1¾	.543	4,560	1¼	.523	3,870
¾	.480	3,920	2¼	.632	5,010	2	.468	3,640	2¾	.595	4,600	1¼	.437	3,820
1	.477	4,450	¾	.550	4,660	1½	.515	3,920	2½	.566	4,910	1¼	.503	3,090
1¼	.477	3,070	2¼	.610	4,560	2	.491	[1] 2,600	2	.582	3,860	--------	--------	--------
½	.465	4,600	1¼	.572	4,010	2¼	.515	3,950	2	.617	4,516	--------	--------	--------
Av. 1.17	.470	4,158	1.62	.610	4,481	1.72	.467	4,090	2.20	.582	4,477	1.34	.506	3,851

[1] Omitted from average.

As in the Kaufman County work, the high strength of the concrete and the uniformity of test results deserve special notice. No effort was made to vary the water content of the batches from which cylinders were taken from that used in normal operation. The significant fact in this series of tests is that two mixers were used. The job was started with a 5-bag machine of the same type as used on the Kaufman County job which was replaced by a new 6-bag paver of a different make. The data secured show no material difference in the efficiency with which these mixers operate. It has not been possible to find any significant difference in the efficiency with which the standard 21E and 27E pavers of the different recognized makes mix concrete, once the materials are in the drum. There is a little difference in the rate at which the materials are fed into the drum and in the case of the older models of one or two of the standard pavers, the drum is charged so slowly that this fact must be taken into consideration in determining the actual mixing time.

Table 6 gives results secured from cylinders taken on another job where the concrete was mixed by the same that the water-cement ratio as determined varied quite a little and that the slump does not always agree with the water-cement ratio. The results of the field determinations of water content on this project are published in spite of the fact that they vary a good deal and in some instances are rather low, because they show the kind of variations almost certain to be encountered on a paving job and the difficulty which is faced in securing uniform water content and uniform concrete. The inspection on this job was far above average, the superintendent for the contractor, a man of outstanding ability, and the contractor, himself an engineer, a man whose first purpose appeared at all times to be the delivery of the best quality of work engineering skill could produce. The bureau's work on this project was done by the same men who secured the data given in Tables 2, 18, and 21. These facts appear to warrant the statement that the control of the major factors affecting strength requires more study in order to devise methods of construction that protect strength and uniformity and at the same time are practical from the production standpoint.

SLOW CHARGING OF MIXER REFLECTED IN RESULTS

Table 7 gives the strength of a number of cylinders taken on another job where the conditions prevailing were quite similar to conditions on the job from which the cylinders listed in Table 6 were taken. In this case the mixer—an old 5-bag machine—was about worn out. The machine charged so slowly—often requiring 20 seconds or more for the complete discharge of the skip—that about 15 seconds should be deducted from the mixing time as recorded to make the results directly comparable with those secured on other jobs. Here, again, it is apparent that 45 seconds of actual mixing is sufficient to develop about all of the strength the mix will produce.

In general, the mixers which have been studied developed practically the full strength of the concrete within 45 seconds after the skip reaches full vertical position—if the charging is slower than normal, that is, if emptying the skip actually takes much over five seconds—this has the effect of reducing the mixing time and, if an arbitrary 45-second mixing period is in use, may have a small adverse effect on strength. It may be well to note, however, that even in this case where the mixer was one of the most dilapidated found on any paving job, the loss of strength as between a

TABLE 7.—*Data on cylinders taken on Federal-aid project 475 in Bowie County, Tex.*

[Mix 1:2:3½; gravel coarse aggregate; Foote mixer in poor condition]

45-second mix		60-second mix		75-second mix		90-second mix		120-second mix		180-second mix	
Slump	Compressive strength	Slump	Compressive strength	Slump	Compressive strength	Slump	Compressive strength	Slump	Compressive strength	Slump	Compressive strength
Inches	*Lbs. per sq. ins.*	*Inches*	*Lbs. per sq. in.*	*Inches*	*Lbs. per sq. in.*	*Inches*	*Lbs. per sq. in.*	*Inches*	*Lbs. per sq. in.*	*Inches*	*Lbs. per sq. in.*
1.25	4,700	1.50	5,610	1.25	5,250	2.50	4,520	2.00	5,490	2.50	5,260
1.25	5,330	1.50	5,450	1.25	5,120	2.50	4,860	2.00	5,330	2.50	5,160
.50	4,700	2.00	5,050	2.50	4,410	5.00	4,740	5.50	4,750	1.50	5,110
.50	5,080	2.00	5,200	2.50	4,230	5.00	4,980	5.50	4,560	1.50	5,460
2.00	4,910	4.75	3,100	--------	--------	2.75	5,160	2.00	4,950	--------	--------
2.00	4,210	4.75	3,950	--------	--------	2.75	5,560	2.00	4,920	--------	--------
Av. 1.25	4,822	2.75	4,727	1.88	4,752	3.42	4,970	3.17	5,000	2.00	5,248

TABLE 8.—*Data on cylinders taken on Federal-aid project 159A in Okmulgee County, Okla.*

[Mix 1:2:3½; gravel coarse aggregate; Koering mixer in good condition]

30-second mix			45-second mix			60-second mix			75-second mix			90-second mix			105-second mix			120-second mix		
Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
--------	0.608	4,740	--------	0.608	4,940	1⅜	0.675	4,860	1 1/16	0.670	5,150	1¾	0.675	5,200	1⅜	0.675	5,400	1	0.595	5,330
¾	.505	5,045	1	.565	4,270	1⅜	.590	5,266	1⅛	.646	5,720	1½	.646	4,845	1	.641	5,320	11/16	.641	4,895
1⅛	.676	4,948	1	.646	6,300	1⅛	.655	4,950	1	.663	5,650	9/16	.516	4,900	¾	.510	5,650	7/16	.510	5,155
11/16	.510	4,750	¾	.578	4,750	1⅜	.655	4,415	1	.578	4,270	11/16	.578	4,210	¾	.506	4,645	9/16	.545	5,495
¾	.506	5,210	1	.506	5,540	1⅜	.620	4,950	1⅛	.598	4,800	11/16	.545	4,265	1	.525	4,645	1⅛	.530	5,000
9/16	.530	4,750	9/16	.571	4,390	¼	.595	4,520	⅝	.620	4,690	1	.678	4,660	1	.636	5,750	11/16	.655	5,465
1 5/16	.631	5,095	5/16	.601	5,210	¾	.588	5,980	11/16	.593	5,610	2⅝	.633	5,800	3	.636	4,845	1 1/16	.565	5,000
11/16	.565	5,400	1¼	.580	[1] 3,600	1	.603	5,000	1 1/16	.628	5,710	1⅜	.624	5,840	11/16	.592	5,210	1¼	.597	4,950
7/16	.590	5,160	1 1/16	.580	5,800	⅝	.590	5,450	1¾	.624	4,865	1 1/16	.607	5,650	2 1/16	.607	5,325	⅞	.607	5,650
1 5/16	.646	4,800	1⅝	.646	4,910	6	.688	3,630	7	.701	5,480	1 1/16	.646	4,160	2	.646	4,135	7	.701	4,060
Av. 0.81	.577	4,990	0.75	.588	5,123	1.49	.626	4,902	1.66	.632	5,194	1.26	.615	4,953	1.42	.597	5,092	1.54	.595	5,100

[1] Poor break, not included in average.

TABLE 9.—*Data on cylinders taken on Oklahoma State-aid project 318 in Okmulgee County, Okla.*[1]

[Mix 1:2:3½; gravel coarse aggregate; Rex mixer in poor condition]

30-second mix			45-second mix			60-second mix			75-second mix			90-second mix			120-second mix			180-second mix		
Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength	Slump	$\frac{W}{C}$	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
1½	0.670	3,560	1	0.547	2,740	1¼	0.606	4,915	1	0.606	4,560	1	0.547	4,500	1¼	0.613	4,880	--------	0.680	4,635
3	.615	3,065	6	.586	2,405	1¼	.586	4,010	¾	.606	4,740	11/16	.593	4,560	4½	--------	4,529	--------	--------	--------
¾	.613	3,380	½	.593	2,920	1¼	.651	4,710	11/16	.615	5,880	11/16	.640	5,625	11/16	.651	5,840	--------	--------	--------
½	.615	3,975	11/16	.640	4,635	¾	.671	4,095	⅞	.646	6,100	5	--------	3,274	1⅛	.671	4,690	1¾	.680	4,635
3	.646	2,970	5/16	.680	4,880	1⅞	.643	5,020	1¾	.651	--------	1/16	.508	4,240	2¾	.643	4,630	--------	--------	--------
2	.508	4,200	1⅞	--------	3,840	½	--------	4,655	3¾	--------	5,087	0	--------	5,017	1/16	--------	5,138	--------	--------	--------
2	--------	3,129	1⅝	--------	4,270	2	--------	4,626	1⅞	.580	4,076	2⅛	--------	4,982	1⅞	.580	4,892	--------	--------	--------
1¾	.586	4,028	--------	--------	--------	--------	--------	--------	1 1/16	.609	4,618	1¼	.586	4,786	--------	--------	--------	--------	--------	--------
5¾	.609	3,189	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Av. 2.25	.607	3,499	1.75	.609	3,670	1.27	.631	4,576	1.53	.616	5,009	1.48	.593	4,623	1.80	.632	4,942	1.75	.680	4,635

[1] Mixer was in very poor condition due largely to concrete being allowed to harden in drum. The material was the same as used on Federal-aid project 159-A, Table 8.

45-second mix as measured from the time the skip reached a vertical position (that is with no allowance for mixing time lost by reason of slow charging) and the longest mix specified by any State for highway paving work, (90 seconds) was less than 4 per cent. For the reasons given above data from this job is not included in the general averages.

Table 8 shows the results secured from a series of cylinders taken on Oklahoma Federal-aid project 159A and broken by the State laboratory. The specified mixing time was one and one-half minutes. The cylinders represent ordinary job conditions as no effort was made to control water content or any other factor affecting the strength of the concrete except the length of the mixing time. A low water content was used and the consistency of the concrete was as well controlled as can be expected with equipment of the present design. There is no significant improvement in strength beyond the one half minute mixing period.

HARDENED CONCRETE IN MIXER DRUM RESULTS IN SLOW MIXING

Table 9 gives results on a project where the general control was poor, the slump often too high and the inside of the drum badly coated with hardened concrete. This resulted in a slow rate of mixing and the table shows that the concrete did not reach full average strength until it had been mixed a minute or more. This confirms what has been known for a long time—that to be fully effective the interior of a mixer drum must be kept clean. Data from this job is not included in the general average.

LONG-TIME MIXING NOT REQUIRED WHERE DUST-COATED LIMESTONE USED

Gravel was used as coarse aggregate on all jobs which have been discussed. Tables 10 and 11 give results secured on jobs where crushed limestone was used as coarse aggregate. Some limestones give off considerable dust when crushed and some of this dust settles on the stone. On the job from which the cylinders shown in Table 10 were secured, the dust was unusually adhesive and it was thought that long-time mixing would yield greater strength than short-time mixing merely because the scrubbing action in the mixer would remove the dust film to a greater extent. That this did not result is apparent from the average strengths for various mixing periods. There is, as a matter of fact, less uniformity in the test data for the materials mixed three minutes than in that mixed 45 seconds. However, the entire series is too short to be indicative of much else than that long mixing did not give any outstanding improvement in strength or in uniformity of test results, even though the material was one that should have brought out any advantage a long mixing time could have.

MAKING THE SLUMP TEST

Table 11 gives results secured on a job where the dust coating on the aggregate was readily observable, but not as bad as on the job previously described. On this job two cylinders were taken from each batch sampled—one at 45 seconds and one at a longer period. Of the 26 pairs, 9 showed a higher strength after a 45-second mix than after a longer mix and 3 showed strength so nearly the same that the difference may be considered negligible. For the balance, 14 pairs, the longer mix gave higher strength, indicating a slight tendency to remove some of the dust layer during the process of mixing. The one-minute mix in this case is about 10 per cent stronger than the 45-second mix, but the one-and-one-fourth-minute mix is only about 5 per cent stronger, so these differences may in both cases be due more to fortuitous breaks on the longer-time cylinders than to a consistent benefit from the longer mixing period.

There is also another factor which may have affected this series. Most mixers segregate the materials a little at the ends of the batch. For some reason the first of a batch is apt to be oversanded while the last cubic foot or so of a batch in extreme cases contains little but coated stone. In general this condition is

TABLE 10.—*Data on cylinders taken on Federal-aid project 130 in Logan County, Okla.*

[Mix 1:2:3½: crushed limestone coarse aggregate; Smith mixer in good condition]

30-second mix			45-second mix			60-second mix			75-second mix			90-second mix			120-second mix			180-second mix		
Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
½	0.60	4,310	½	0.60	4,525	¾	0.60	4,980	¾	0.60	5,320	¾	0.60	4,605	1	0.60	4,715	1	0.60	4,425
¾	.67	4,850	¾	.67	4,650	1	.67	5,320	1	.71	[1] 3,060	1	.67	4,845	⅜	.67	5,855	¾	.67	4,455
⅞	.71	4,270	⅝	.71	4,810	1	.71	4,745	1¼	.71	4,800	¾	.71	4,315	1¾	.70	4,600	1⅛	.70	5,225
¾	.69	4,460	¾	.69	4,320	¾	.69	5,120	1	.69	4,010	1	.69	3,918	1	.69	[1] 3,590	1⅛	.69	[1] 3,665
½	.78	4,750	½	.78	4,855	1⅜	.80	4,340	1⅛	.78	[1] 2,340	⅞	.78	4,500	⅞	.78	4,885	¾	.78	4,065
½	.71	5,215	¾	.71	5,650	1	.71	4,235	1	.71	4,855	⅞	.71	4,675	1	.71	5,215	1	.71	[1] 2,600
Av. 0.57	.693	4,642	0.65	.693	4,802	0.98	.697	4,790	1.02	.700	4,746	0.98	.693	4,476	1.00	.692	5,054	0.96	.692	4,542

[1] Omitted from average because of coated aggregate.

Table 11.—*Data on cylinders taken on Federal-aid project 229C in Boone County, Mo.*

[Mix 1:2:3½; crushed limestone coarse aggregate; Koehring mixer in good condition]

(In pounds per square inch)

30-second mix, compressive strength	45-second mix, compressive strength	60-second mix, compressive strength	75-second mix, compressive strength	90-second mix, compressive strength	120-second mix, compressive strength	180-second mix, compressive strength
3,008	4,110	2,880	4,305	4,430	3,379	3,118
3,505	4,100	3,846	4,780	4,200	4,190	1,940
2,500	4,909	2,958	3,821	4,220	4,070	4,670
3,540	3,850	4,020	3,950		3,530	
3,310	3,390	4,818	3,800		3,182	
	3,500	2,700	3,510			
	3,700	4,419	3,718			
	3,800	4,103	2,870			
	3,820	3,184	3,350			
	3,420	4,300	3,598			
	3,040	4,730	3,600			
	3,300	3,300	3,575			
	3,418	3,758	4,335			
	3,228	3,610	4,779			
	4,098	3,380				
	4,257	4,292				
	3,418	4,184				
	4,431	3,740				
	3,332	4,248				
	3,828					
	4,531					
	3,250					
	3,700					
	3,254					
	4,640					
Av. 3,172	3,773	3,817	3,857	4,283	3,670	3,243

more conspicuous where wet concrete is being mixed than with concrete of proper consistency. On this job the inspector was so strongly opposed to the use of the short-time mix that the least possible amount of material in excess of actual needs for samples was discharged from the mixer for the 30-second and 45-second specimens. As a result, the 45-second cylinders are possibly not quite as representative as where samples were taken from the center of a batch as discharged from the bucket or from a larger sample run out onto the subgrade.

TESTS ON OTHER JOBS CONFIRM RELATION BETWEEN MIXING TIME AND STRENGTH

Table 12 gives results obtained on a series of cylinders taken by the bureau's representatives on another project. In this case the 45-second concrete appears to be a little better than that mixed a longer time but it is not believed that the apparent difference of about 200 pounds in the average strength is due to anything more than a fortuitous series of breaks. The high strength of the 30-second concrete should be noted.

Table 13 gives the results of tests on cylinders, beams, and cores made by the regular inspector on another section of this same project where the regular one-minute mix was used. The beams were broken in the field and no doubt vary somewhat more than would be expected had they been handled in a well equipped laboratory. The method used was that devised by the Illinois State highway laboratory.[3] The longer series of cylinders is in substantial agreement with the results obtained by the bureau's engineers as was the case in the Kaufman Co. work reported in Tables 2 and 4.

Table 14 gives the results of another series of tests. In this case the 60-second cylinders gave little higher strength than the 45-second cylinders and this is to be viewed in the same way that the reverse condition was viewed on the preceding project. In Table 14 the

[3] Clemmer, H. F. Comparison of the Transverse and Compressive Tests of Concrete. Public Roads, vol. 7, No. 3, May, 1926.

Table 12.—*Data on cylinders taken on Federal-aid project 448B in Clay County, Tex.*

[Mix 1:2:3½; gravel coarse aggregate; Koehring mixer in good condition]

(In pounds per square inch)

30-second mix, compressive strength	45-second mix, compressive strength	60-second mix, compressive strength	90-second mix, compressive strength	120-second mix, compressive strength
5,520	[1] 3,550	5,720	4,900	4,160
4,660	4,350	4,200	3,410	4,700
5,000	5,440	5,620	5,220	4,320
5,120	5,070	5,130	4,360	3,850
5,160	3,910	4,900	4,900	4,480
	5,480	4,630		
	5,810	3,990		
	5,060	4,760		
	5,240	3,520		
	4,740	4,790		
	5,080	4,620		
	5,120	4,360		
	4,080	4,230		
Av. 5,092	4,948	4,651	4,558	4,302

[1] Omitted from average because of flat rock in center of cylinder.

Table 13.—*Data on cylinders, beams and cores taken on Federal-aid project 448B in Clay County, Tex., by State inspector. All concrete mixed 1 minute*

[Cores tested at ages of 50 to 70 days and averaging approximately 60 days]

Cylinders and beams			Cores	
Station	Compressive strength of cylinders	Modulus of rupture of beams	Station	Compressive strength
	Lbs. per sq. in.	*Lbs. per sq. in.*		*Lbs. per sq. in.*
162+50	4,380		165+00	6,200
174+00	4,253	571		
180+50	4,440	709	184+80	6,060
191+00	5,410	722	186+00	5,400
			193+00	4,910
201+00	6,050	590	204+29	5,970
			207+73	5,970
212+00	4,093	745	208+80	5,730
			208+95	4,720
224+00	5,227			
234+00	4,720	674	235+15	6,060
240+00	5,070	697		
249+50	4,657	764		
259+00	4,437	691	261+00	5,440
268+50	4,723	865		
276+00	5,630	753		
285+00	4,327	642	287+00	5,900
295+50	[1] 2,997	456		
304+50	4,593	640		
312+00	[1] 3,493	606	313+00	5,340
320+00	4,500	565		
322+00	4,637	540		
332+25	4,517	534		
342+00	4,653	748	340+00	6,200
352+00	4,200	730		
356+25	4,573	680		
362+00	5,003	573	366+00	5,850
376+00	3,207	447		
Average	4,665	650		5,696

[1] Poor breaks, not included in the average.

figures on the same horizontal line represent cylinders from the same batch. No reason can be given with certainty as to why there should be so much variation in strength.

Tables 15 and 16 give the results of still another series of tests on mixing time made in Grant County, Okla. Results of tests on cylinders secured on this job might create the impression that long-time mixing has improved the strength of the concrete, though the 45-second concrete is of good quality, were it not for the beam tests which entirely negative the apparent deficiency of some of the 45-second concrete as indicated by the cylinders.

TABLE 14.—*Compressive strength of cylinders taken on a job in Hillsdale County, Mich.*

[Mix 1:2:3.4; gravel coarse aggregate; Koehring mixer in fair condition]

Crushing strength: 30-second mix	45-second mix	60-second mix	75-second mix	90-second mix	120-second mix	180-second mix	Slump of 1-minute mix	W/C
Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*	
	3,756	5,185					½	0.58
3,750	3,380	5,220	5,270	5,010	5,160	4,450	1¾	.68
3,975	5,380	5,210	5,190	5,240	5,150	3,465	1¾	.64
4,320	4,490	4,955		4,030		4,890	1¼	.67
4,087	4,755	5,026	2,227	3,958	3,134	4,402	½	.61
4,910	5,800	4,435	3,195	3,650	4,175	2,900	¼	.53
			4,100		4,515		1½	.70
3,980	3,990	4,280	3,090	3,590	4,040		1½	.56
3,634	4,295	2,800	3,530	2,530	3,115	3,170	¼	.43
3,315	4,455	4,485	3,475	4,220	3,610	5,350	¼	.43
2,970	3,930	3,130	2,510	3,080	3,990	5,300	¼	.44
4,400	5,260	4,450	4,190	3,225	5,780	4,070	½	.52
3,790	3,050	4,710			4,950		¼	.44
2,675	3,550	4,220			3,550		½	.55
3,345	3,550	3,690			2,780		1¼	.58
3,750	4,160	4,640			4,530		2	.58
3,370	3,140	3,060			3,445		1	.57
	2,980	2,880			3,660		¾	.55
3,040	3,390	3,290			4,310		¼	.54
Av 3,707	4,073	4,204	3,678	3,853	4,111	4,222	.85	.558

SPECIMENS REMOVED FROM MOLDS AND PLACED FOR CURING UNDER THE SAME CONDITIONS AS THE PAVEMENT, OKLAHOMA FEDERAL-AID PROJECT 148E

A DAY'S RUN OF BEAMS AND CYLINDERS, ANDERSON COUNTY, TENN.

Table 17 gives results of tests of a long series of cylinders taken in Clay County, Tex. Some very high strength concrete was secured from 30-second mixes and, in general, additional mixing showed no advantage. The 30-second concrete is somewhat lacking in uniformity of test results but other mixes are satisfactory in this respect, as well as in strength. No special significance is attached to the fact that 45-second concrete is stronger than that produced by longer mixing. The difference between 45-second concrete and 90-second concrete is only about 6 per cent—not a significant amount unless generally observed throughout a long series of tests.

TABLE 15.—*Strength of cylinders and beams cured by various methods on Federal-aid project 148E, Grant County, Okla.*

[Mix 1:2:3½; limestone coarse aggregate; Rex mixer in good condition]

Curing	Tests of cylinders: 30-second mix: Cylinders	30-second mix: Compressive strength	45-second mix: Cylinders	45-second mix: Compressive strength	60-second mix: Cylinders	60-second mix: Compressive strength	90-second mix: Cylinders	90-second mix: Compressive strength	180-second mix: Cylinders	180-second mix: Compressive strength	Tests of beams: 30-second mix: Beams	30-second mix: Modulus of rupture	45-second mix: Beams	45-second mix: Modulus of rupture	60-second mix: Beams	60-second mix: Modulus of rupture	90-second mix: Beams	90-second mix: Modulus of rupture	180-second mix: Beams	180-second mix: Modulus of rupture
	Number	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*	*Number*	*Lbs. per sq. in.*
Calcium chloride admixed	5	3,678	10	4,264	10	4,720	10	4,768	5	5,123	2	404	5	553	5	556	4	575	2	541
No treatment			10	4,659	10	5,251	10	4,988					5	605	2	558	5	603		
Surface treated with calcium chloride			10	3,829	10	3,580	10	3,835					5	552	2	528	5	514		
Moist earth			6	[1] 4,450	6	[1] 4,403	6	[1] 5,093					5	640	2	601	5	665		
Average		3,678		4,301		4,489		4,671		5,123		404		588		561		589		541

[1] Results from a group of cylinders made on another part of the job showed low strengths from some unknown cause and are not reported.

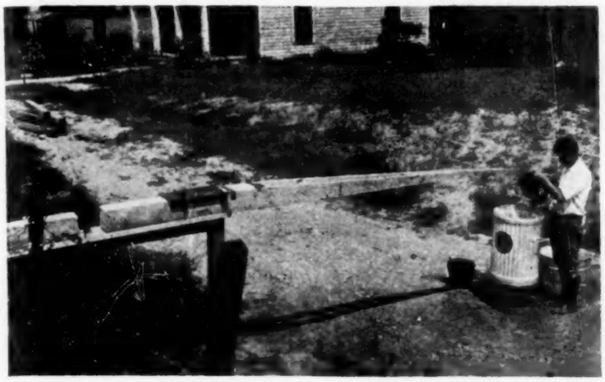
213—28——2

TABLE 16.—*Strength of cylinders and beams cured by various methods on Federal-aid project 148E in Grant County, Okla.*

[Mix 1: 2: 3½: limestone coarse aggregate; Rex mixer in good condition]

30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
Slump	$\frac{W}{C}$	Compressive strength of cylinders	Modulus of rupture of beams	Slump	$\frac{W}{C}$	Compressive strength of cylinders	Modulus of rupture of beams	Slump	$\frac{W}{C}$	Compressive strength of cylinders	Modulus of rupture of beams	Slump	$\frac{W}{C}$	Compressive strength of cylinders	Modulus of rupture of beams	Slump	$\frac{W}{C}$	Compressive strength of cylinders	Modulus of rupture of beams
Inches		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*
CURED BY COVERING WITH WET EARTH																			
				0.44	0.60	4,180 4,910	662	0.75	0.60	4,890 4,800 5,030		1.25	0.60	4,350 4,725	597				
				.75	.60	4,960 4,460	681	1.25	.60	3,670 4,360 3,670		.75	.60	5,870 5,250	763				
				.75	.60	4,020 4,170	615	1.20	.61	3,600 2,810 2,490 3,600	670 531	1.06	.60	5,410 4,950	672				
				1.00	.61	2,990 3,220	640					.20	.61	2,590 2,950	599				
				2.25	.61	2,810 2,480	600					2.50	.61	3,180 3,830	696				
Average				1.04	.604	3,820	640	1.08	.604	3,892	601	1.15	.604	4,311	665				
CURED IN OPEN AIR WITHOUT COVER [1]																			
				1.20	0.55	4,872 4,710	509	1.31	0.55	5,230 5,080 5,140		0.75	0.55	5,220 5,360	604				
				1.00	.55	5,585 5,325	712	1.00	.55	5,560 6,040 5,960		1.31	.55	5,325 4,250	743				
				.88	.55	5,685 5,310	694	1.00	.53	4,945 5,090	548	2.25	.55	4,945 4,720	585				
				1.50	.53	3,635 3,450	510	.58	.53	4,635 4,830	567	.44	.53	5,250 5,460	563				
				1.58	.53	4,145 3,870	509					1.75	.53	4,820 4,530	518				
Average				1.23	.54	4,659	605	.95	.54	5,251	558	1.30	.54	4,988	603				
CALCIUM CHLORIDE ADMIXED—2 POUNDS PER BAG OF CEMENT																			
4.50	0.59	2,609	449	1.62	0.59	2,706 4,496	574	0.25	0.59	4,496 4,630	542 612	2.00	0.59	4,780 4,855	535	2.75 1.37	0.59 .59	4,855 4,945	480
5.75	.59	2,382	359	2.00	.59	3,778 2,790		1.50	.59	5,100 5,070	567	1.57	.59	4,215 4,220		.13 .75 .63	.59 .55 .55	5,160 5,745 4,910	602
1.37	.59	4,460		1.88	.59	4,245 4,385		1.25	.59	5,215 4,900		.88	.59	4,720 4,790	615				
3.06	.55	4,650		1.25	.55	4,640 5,395	591 524	2.50	.55	4,365 4,070	522	1.50	.55	4,965 5,785	623				
.25	.55	4,290		.75	.55	4,740 5,465	501 574	1.20	.55	4,420 4,935	539	1.50	.55	4,855 4,490	528				
Average		3,678	404	1.50	.57	4,264	553	1.34	.57	4,720	556	1.49	.57	4,768	575	1.12	.57	5,123	541
CALCIUM CHLORIDE COVERING—2 POUNDS PER SQUARE YARD																			
				0.70	0.52	3,725 3,270	449	0.44	0.52	3,640 4,255 4,280		0.70	0.52	4,245 4,160	477				
				.81	.52	4,350 4,400	602	1.00	.52	4,160 3,730 3,415		1.25	.52	3,900 3,650	565				
				.37	.52	4,460 4,220	566	.93	.61	2,660 2,840	486	2.06	.52	4,080 4,185	499				
				1.25	.61	3,170 3,160	542	1.75	.61	3,460 3,360	569	1.25	.61	3,330 3,000	569				
				1.12	.61	3,530 4,000	599					1.87	.61	4,195 3,600	459				
Average				.85	.56	3,829	552	.97	.56	3,580	528	1.43	.56	3,835	514				

[1] Several heavy rains during curing period.



Breaking Beams on the Job in Anderson County, Tenn.

Throughout this series the 45-second concrete is sometimes the strongest, sometimes the 60-second concrete, and sometimes the 90-second concrete, but the differences are always small and this can only be interpreted as indicating that mixing time within the limits given is a neglible factor in strength. In other words, differences in averages are less than the reported differences between cylinders in the same group. When these facts are examined in the light of the well-recognized margin of error in testing methods and in testing machines, the conclusion that small differences such as those developed on this project, are without significance unless often repeated and clearly apparent in the general average, is inevitable.

Tables 18 and 19 cover two series of cylinders, neither of which requires special comment.

Table 17.—*Data on cylinders secured on Federal-aid project 449A in Clay County, Tex.*

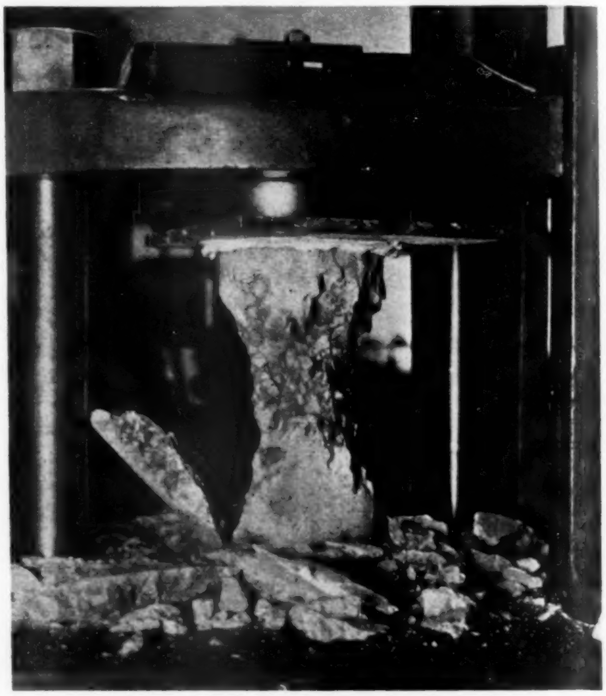
[Mix 1:2:3½; stone and gravel coarse aggregate; Koehring mixer in good condition]

30-second mix			45-second mix			60-second mix			90-second mix			120-second mix		
Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength	Slump	W/C	Compressive strength
Inches		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*
4.50	0.639	4,160	0.50	0.575	5,020	4.75	0.645	5,310	4.00	0.639	4,540	1.25	0.620	5,080
4.50	.661	4,340	4.00	.610	5,180	4.75	.645	3,580	3.00	.647	4,570	3.50	.668	4,240
4.50	.647	4,760	1.75	.624	5,290	4.75	.645	5,340	2.00	.617	4,600	2.00	.620	4,790
2.50	.554	4,460	3.50	.618	5,000	2.50	.712	6,020	3.00	.572	4,970	2.50	.540	5,820
4.00	.612	3,900	3.00	.618	4,960	2.50	.712	5,900	.25	.532	6,950	2.50	.527	5,600
3.50	.637	4,210	6.50	.738	5,650	2.50	.712	5,670	6.00	.650	4,070	1.00	.530	5,920
.75	.537	4,390	.75	.647	6,400	6.00	.666	4,580	3.25	.554	4,780	3.00	.537	4,830
.50	.582	5,290	2.50	.685	5,620	1.50	.639	5,030	3.25	.607	5,230	2.50	.583	4,820
.75	.572	4,240	2.50	.692	5,770	1.50	.639	4,780	2.00	.594	4,450	2.25	.594	4,470
4.50	.570	4,720	1.00	.698	4,870	1.50	.639	5,170	2.25	.583	5,850	3.00	.583	4,210
1.75	[1] .318	6,150	4.00	.639	5,440	2.00	.610	5,340						
3.00	.415	6,320	3.00	.647	4,640	2.25	.647	4,770						
5.50	.434	5,390	1.50	.608	6,380	2.25	.647	4,450						
.75	[1] .356	5,480	2.00	.551	5,370	2.25	.647	4,560						
.75	[1] .316	5,870	2.00	.599	6,330	2.50	.620	6,050						
.50	.486	7,770	5.75	.668	4,400	2.50	.620	3,680						
1.25	.470	7,250	5.00	.556	4,750	2.50	.620	4,560						
1.50	.470	6,700	2.50	.583	5,430	2.50	.620	4,070						
1.00	.470	7,470	2.50	.580	4,780	4.00	.572	4,550						
2.75	.542	6,420	4.50	.570	4,910	2.00	.540	4,640						
						2.00	.540	4,430						
						2.00	.540	4,760						
						4.00	.586	5,660						
						1.50	.540	6,850						
						1.50	.540	6,530						
						1.50	.540	5,710						
						3.00	.610	5,610						
						4.00	.556	4,960						
						4.00	.556	5,260						
						4.00	.556	5,030						
						1.25	.551	4,896						
						3.00	.610	5,440						
						2.50	.594	4,250						
						2.25	.570	4,500						
						1.00	.482	6,040						
						1.00	.482	6,940						
						1.00	.482	6,620						
						.50	[1] .276	6,540						
						.50	[1] .276	7,220						
						.50	[1] .276	6,490						
						2.00	.570	4,690						
						2.00	.570	4,340						
						2.00	.570	4,680						
						2.00	.594	4,690						
						2.00	.594	4,340						
						2.00	.594	4,690						
						2.50	.596	5,090						
						2.50	.596	4,160						
						2.50	.596	4,970						
						2.50	.549	5,220						
						2.50	.549	5,180						
						2.50	.549	4,920						
Av. 2.44	.546	5,464	2.94	.625	5,310	2.43	.592	5,168	2.90	.599	5,001	2.35	.580	4,978

[1] Probably an incorrect result.

DATA FROM A NUMBER OF JOBS SUPPORT CONCLUSION AS TO MIXING TIME

Table 20 gives the records on a series of batches of concrete all of which were carefully located in the pavement and from which cores were subsequently taken. The average strength of the 45-second cores is 1 per cent below the mean for the series of cores. The 60-second cylinders are 1 per cent above the mean for the cylinders and the 90-second cylinders at the mean. Variations between maximum and minimum strength,



Breaking a Test Cylinder in the Laboratory of the University of Missouri

Table 18.—*Data on cylinders secured on State-aid project 507 in Berkeley County, S. C.*

[Mix 1: 2: 3½; stone coarse aggregate; Koehring mixer in good condition]

60-second mix		75-second mix		90-second mix		120-second mix	
W/C	Compressive strength	W/C	Compressive strength	W/C	Compressive strength	W/C	Compressive strength
	Lbs. per sq. in.		*Lbs. per sq. in.*		*Lbs. per sq. in.*		*Lbs. per sq. in.*
0.624	3,180	0.608	3,220	0.608	3,150	0.631	2,800
.660	2,750	.608	3,160	.608	3,020	.631	2,540
.660	2,860	.608	3,140	.608	2,590	.631	2,470
.660	3,070	.591	2,860	.631	2,300	.649	2,610
.586	2,900	.591	2,830	.631	2,940	.649	2,620
.586	2,960	.591	2,860	.631	2.670	.649	2,480
.586	2,360	.607	2,870	.602	2,900	.642	2,980
.608	2,830	.607	3,020	.602	3,230	.642	3,010
.608	2,790	.607	3,060	.602	3,360	.642	3,120
.608	2,740	.602	2,690	.613	3,540	.624	2,100
.597	3,050	.602	2,710	.613	2,060	.624	2,520
.597	3,200	.602	3,150	.613	2,570	.624	3,290
.597	2,680	.613	3,180	.620	2,870	.631	2,720
.551	2,850	.613	3,080	.620	3,290	.631	2,830
.551	2,800	.613	2,780	.620	2,850	.631	3,460
.551	3,210	.620	3,030	.631	3,280	.633	2,980
.624	2,460	.620	3,240	.631	3,120	.633	3,180
.624	2,840	.620	2,770	.631	3,390	.633	2,350
.624	2,530	.613	3,180	.642	3,420	.645	2,220
.626	3,460	.613	3,400	.642	2,950	.645	2,290
.626	2,700	.613	3,200	.642	2,970	.645	2,400
.626	3,580	.642	3,980	.633	3,250	.645	2,190
.608	3,970	.642	3,610	.633	3,950	.645	[1] 1,490
.608	3,660	.642	3,700	.633	2,990	.645	2,870
.608	3,390	.631	[1] 1,420	.655	3,100		
.608	3,560	.631	[1] 1,520	.655	2,930		
.608	3,270	.631	[1] 1,570	.655	2,760		
.608	3,000	.615	2,670				
.631	2,970	.615	2,510				
.631	2,940	.615	2,820				
.631	3,920	.638	3,730				
.631	2,880	.638	2,970				
.631	1,930	.638	3,280				
.631	2,870	.666	2,680				
.651	2,740	.666	3,000				
.651	4,160	.651	3,700				
.651	4,290	.651	3,400				
.651	3,600	.651	3,370				
.651	2,720	.651	3,450				
.651	2,060	.651	3,480				
.651	2,460	.651	3,950				
.651	2,450	.651	4,760				
.638	1,500	.666	3,160				
.638	2,340	.666	3,100				
.638	2,800	.666	3,140				
.615	2,780	.631	3,000				
.615	2,630	.631	2,350				
.615	2,950	.626	2,910				
.642	2,850	.626	3,140				
.642	3,160	.626	2,890				
.642	2,640	.633	2,780				
.642	2,580	.633	2,760				
.619	2,230	.633	2,860				
.619	2,150	.638	2,280				
.619	2,330	.638	2,660				
.619	1,955	.638	3,000				
.619	2,560	.638	2,650				
.619	2,760	.654	2,690				
.619	3,280	.654	3,020				
.619	2,900	.564	2,360				
.639	3,860	.654	3,100				
.639	4,600	.619	2,860				
.639	3,900	.619	3,210				
.639	4,400	.619	3,025				
.653	3,910	.619	2,660				
.653	4,120	.672	2,500				
.653	4,320	.672	2,810				
.653	3,280	.672	3,300				
.657	2,870	.672	3,370				
.657	2,700	.660	2,740				
.657	3,050	.660	2,190				
.657	2,950	.660	2,940				
.633	4,010	.660	2,890				
.633	4,960	.634	3,410				
.633	4,500	.634	3,330				
.633	3,940	.634	2,630				
		.634	3,530				
		.651	4,400				
		.651	3,700				
Av. .627	3,084	.634	3,017	.626	3,017	.638	2,697

[1] Apparently incorrect and omitted from average

Table 19.—*Data on cylinders secured on Federal-aid project 174 B-2 in Hughes County, Okla.*

[Mix 1 : 2 : 3½; gravel coarse aggregate; Koehring mixer in good condition]

30-second mix		45-second mix		60-second mix	
W/C	Compressive strength	W/C	Compressive strength	W/C	Compressive strength
	Lbs. per sq. in.		*Lbs. per sq. in.*		*Lbs. per sq. in.*
0.669	4,110	0.678	4,290	0.720	3,490
.660	4,220	.660	4,500	.660	4,320
.666	4,460	.642	4,100	.728	3,470
.633	3,230	.622	3,450	.644	5,100
.573	4,640	.630	4,730	.598	5,350
.676	4,050	.656	3,890	.646	4,710
.597	4,150	.620	4,140	.638	4,180
.724	4,990	.662	5,220	.662	4,520
.660	4,890	.626	4,870	.662	4,460
.644	4,700	.644	4,800	.644	4,800
Av. 0.650	4,344	.644	4,399	.660	4,440

90-second mix		120-second mix	
W/C	Compressing strength	W/C	Compressing strength
	Lbs. per sq. in.		*Lbs. per sq. in.*
0.656	3,850	0.633	4,100
.650	4,540	.642	4,930
.662	3,800	.662	4,910
.586	5,200	.640	4,710
.575	4,800	.642	3,770
.633	4,720	.646	4,530
.597	3,890	.597	3,350
.638	4,270	.662	5,160
.656	4,540	.615	4,260
.644	4,680	.644	4,220
Av. 0.630	4,429	.638	4,394

TABLE 20.—*Compressive strength of cores and cylinders taken on Federal-aid projects 174B-2 and 188A in Hughes and Seminole Counties, Okla.*

[The cores and cylinders on each line of the table were taken from the same batch. Cores were tested at an age of approximately 90 days. Mix 1:2:3½; gravel coarse aggregate; Koehring mixer in good condition]

(In pounds per square inch)

45-second mix		60-second mix		90-second mix	
Cylinders	Cores	Cylinders	Cores	Cylinders	Cores
5,630	5,700	5,030	4,980	5,540	7,725
5,580	5,100	5,670	5,960	3,230	5,185
4,420	5,490	5,440	5,145	5,125	6,350
4,710	7,690	5,060	6,425	4,210	5,290
3,710	5,110	5,395	6,010	5,300	6,500
4,850	5,895	4,620	5,620	4,980	4,978
4,380	6,465	4,790	6,280	4,930	6,724
5,230	8,078	4,910	6,040	6,250	8,620
5,590	6,331	5,110	5,590	4,750	5,517
4,360	5,043	5,520	6,370	4,320	5,127
5,165	4,740	4,960	5,603	5,790	4,425
5,290	5,150	4,500	6,340	5,280	5,545
5,240	5,872	4,080	6,213	5,080	6,120
		3,750	7,048		
		5,690	8,189		
		5,580	5,702		
		5,360	5,894		
		5,650	5,851		
		4,800	5,425		
		4,920	5,732		
		4,600	5,390		
		4,420	5,740		
		4,360	4,365		
		5,280	6,330		
		5,820	6,000		
		5,570	6,224		
Av. 4,935	5,897	5,034	5,941	4,983	6,008

MAXIMUM VARIATIONS

	45-second mix	60-second mix	90-second mix
Cylinders:			
Maximum strength	5,630	5,820	6,250
Minimum strength	3,710	3,750	3,230
Difference	1,920	2,070	3,020
Difference, per cent	34	36	48
Cores:			
Maximum strength	8,078	8,189	8,620
Minimum strength	4,740	4,365	4,425
Difference	3,338	3,824	4,195
Difference, per cent	41	47	49

both in cores and in cylinders, are least at 45 seconds and greatest at 90 seconds.

Table 21 shows the results of tests made to determine if the rate at which good concrete increases in strength is affected by the mixing time. Four cylinders were

ONE OF THE OUTFITS USED FOR DRILLING CORES

TABLE 21.—*Results of tests made to determine effect of mixing time on rate of increase in strength. Cylinders made on Federal-aid projects 174B-2 and 188A in Hughes and Seminole Counties, Okla.*

[In pounds per square inch]

Crushing strength, 45-second mix at—				Crushing strength, 60-second mix at—				Crushing strength, 90-second mix at—			
10 days	14 days	21 days	28 days	10 days	14 days	21 days	28 days	10 days	14 days	21 days	28 days
3,745	4,075	4,480	5,630	3,445	4,060	4,965	5,030	3,125	4,220	5,145	5,540
3,200	4,145	4,360	5,580	4,055	3,995	5,070	5,670	[1] 2,275	2,515	2,730	3,230
2,945	3,470	4,395	4,420	3,360	3,830	4,130	5,440	3,665	4,180	5,130	5,125
3,585	4,200	4,370	4,710	3,785	3,475	4,365	5,060	3,710	3,260	4,640	4,210
2,340	3,330	4,530	3,710	3,825	4,060	4,910	5,395	3,950	4,220	5,280	5,300
4,140	4,530	4,960	4,850	3,675	4,190	5,110	4,620	3,695	4,430	4,780	4,980
3,200	3,590	4,180	4,380	3,245	3,960	4,200	4,790	3,295	4,210	4,240	4,930
4,100	4,800	4,730	5,230	3,170	3,170	4,580	4,910	4,310	4,730	5,200	6,250
3,830	4,350	5,280	5,590	3,960	4,085	4,710	5,110	3,745	4,305	4,900	4,750
3,850	4,160	4,550	4,360	4,310	4,450	5,410	5,520	3,560	4,010	4,850	4,320
3,560	4,360	4,390	5,165	4,025	4,640	4,610	4,960	2,670	4,090	5,360	5,780
3,670	4,570	4,760	5,290	3,555	3,780	4,220	4,500	3,810	4,070	5,180	5,280
3,920	4,210	5,045	5,240	2,765	3,595	3,750	4,080	3,690	4,440	4,175	5,080
				3,555	3,635	4,220	3,750				
				4,200	4,915	5,240	5,690				
				4,220	4,640	4,970	5,580				
				3,185	4,250	4,890	5,360				
				3,815	4,375	5,270	5,650				
				3,585	4,170	4,440	4,800				
				3,875	3,950	4,870	4,920				
				3,900	4,560	5,280	4,600				
				2,810	3,970	5,140	4,420				
				3,410	3,350	4,300	4,360				
				3,850	4,350	4,820	5,280				
				4,020	4,330	4,990	5,820				
				4,540	4,730	5,210	5,570				
Av. 3,545	4,138	4,617	4,935	3,698	4,097	4,757	5,034	[1] 3,500	4,054	4,739	4,983

[1] Poor break which if omitted changes average to 3,602.

taken from each batch of concrete selected, and broken at ages of 10, 14, 21, and 28 days. There is no significant difference in the rate at which concrete mixed for various periods has increased in strength.

Tables 22 and 23 give data from jobs in South Carolina and in Kansas.

TABLE 22.—*Compressive strength of cylinders taken on Federal-aid project 243A, Spartanburg, S. C.*

[Mix 94 : 170 : 370 by weight; crushed stone coarse aggregate; Foote mixer in good condition; average slump one-half inch]

(In pounds per square inch)

45-second mix	60-second mix	75-second mix	45-second mix	60-second mix	75-second mix
3, 490	3, 050	2, 990	2, 715	3, 395	3, 395
3, 165	2, 780	2, 950	3, 790	3, 780	3, 510
3, 850	3, 610	3, 770	2, 890	3, 195	3, 550
3, 010	3, 090	3, 590	-------	2, 895	3, 245
3, 730	3, 985	3, 950	3, 090	3, 675	3, 795
3, 290	3, 310	2, 990	3, 655	3, 475	3, 240
3, 110	3, 390	3, 330	3, 390	3, 250	3, 810
3, 450	3, 375	2, 995	3, 770	3, 215	4, 180
3, 335	3, 415	4, 000			
3, 375	3, 230	3, 655	Av. 3, 330	3, 311	3, 506
2, 840	2, 790	3, 675			

TABLE 23.—*Data on cylinders taken on Federal-aid project 360A in Johnson County, Kans.*

[Mix 1 : 2 : 3½; limestone coarse aggregate; Foote mixer in fair condition]

45-second mix		60-second mix		90-second mix	
$\frac{W}{C}$	Compressive strength	$\frac{W}{C}$	Compressive strength	$\frac{W}{C}$	Compressive strength
	Lbs. per sq. in.		*Lbs. per sq. in.*		*Lbs. per sq. in.*
0. 661	4, 416	0. 675	4, 734	0. 675	5, 811
. 661	4, 522	. 675	4, 769	. 675	4, 875
. 657	5, 281	. 669	4, 928	. 713	5, 016
. 657	5, 246	. 669	4, 769	. 713	4, 981
. 657	4, 027	. 669	5, 145	. 714	5, 122
. 657	4, 946	. 669	4, 734	. 714	4, 486
. 715	4, 274	. 666	5, 122	. 701	5, 458
. 715	3, 674	. 666	4, 751	. 701	5, 476
. 724	5, 122	. 661	5, 511	. 687	6, 288
. 724	4, 928	. 661	4, 840	. 687	6, 112
. 679	4, 628	. 668	5, 158	. 672	4, 098
. 679	4, 204	. 668	4, 964	. 672	3, 921
. 668	5, 600	. 675	5, 511	. 672	4, 857
. 668	4, 946	. 675	5, 211	. 672	4, 159
. 663	5, 440	. 684	5, 370	. 684	5, 052
. 663	3, 833	. 684	5, 476	. 684	4, 963
. 663	4, 981	. 684	5, 087	. 678	4, 910
. 663	4, 416	. 684	4, 734	. 678	4, 910
. 663	4, 610	. 684	4, 487	. 684	5, 458
. 663	3, 939	. 684	4, 310	. 684	5, 450
. 645	5, 017	. 652	5, 547	. 652	5, 405
. 645	5, 599	. 652	5, 193	. 652	5, 052
. 666	4, 346	. 652	5, 900	. 652	4, 593
. 666	3, 674	. 652	5, 193	. 652	4, 204
. 657	5, 617	. 654	6, 006	. 652	4, 875
. 657	4, 767	. 654	5, 290	. 652	4, 346
. 652	4, 910	. 654	6, 289	. 662	4, 610
. 652	4, 593	. 654	5, 299	. 662	3, 992
. 657	5, 953	. 654	6, 112	. 638	5, 229
. 657	5, 600	. 654	4, 169	. 638	5, 087
Av. . 668	4, 770	. 667	5, 153	. 676	4, 960

Average for 15 cylinders	Compressive strength		
	45-second mix	60-second mix	90-second mix
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Cured with calcium chloride	4, 580	4, 920	4, 800
Cured in damp earth	4, 948	5, 367	5, 119

Tables 24 and 25 merely add to the data presented. Neither is of special significance.

TABLE 24.—*Compressive strength of cylinders taken on a job in Hillsdale County, Mich.*

[Mix 1:2:3.4; gravel coarse aggregate; Rex mixer in fair condition]

(Pounds per square inch)

Mixing time in seconds							Slump (1-minute mix)	$\frac{W}{C}$	Fineness modulus
30	45	60	75	90	120	180			
							Inches		
2, 244	3, 147	4, 449	3, 887	3, 102	3, 926	3, 692	1¾	0. 74	5. 90
2, 020	3, 125	3, 480	3, 935	3, 445	4, 055	4, 660	1¼	. 68	5. 60
2, 780	2, 550	2, 965	3, 210	2, 871	2, 859	3, 380	-------	. 90	5. 79
3, 595	3, 140	2, 835	2, 770	3, 419	2, 845	2, 815	-------	. 80	5. 76
3, 000	3, 720	3, 440	3, 960	3, 680	4, 285	4, 040	-------	. 70	5. 82
3, 295	3, 425	4, 795	-------	-------	4, 880	-------	2	. 58	5. 88
2, 900	3, 880	4, 530	-------	-------	4, 625	-------	1½	. 50	5. 88
2, 800	4, 090	3, 840	-------	-------	4, 670	-------	1½	. 50	5. 88
2, 711	2, 409	2, 642	-------	-------	2, 622	-------	1	. 49	5. 78
3, 307	4, 450	3, 238	-------	-------	3, 675	-------	1	. 49	5. 78
1, 657	2, 687	4, 000	-------	4, 000	3, 678	-------	1¾	. 54	5. 78
3, 095	4, 085	3, 270	-------	-------	3, 642	-------	1¼	. 52	5. 77
2, 580	3, 420	2, 700	-------	-------	3, 710	-------	1¼	. 52	5. 77
2, 870	4, 100	3, 170	-------	5, 000	4, 545	-------	¾	. 56	5. 80
2, 794	2, 408	3, 355	-------	4, 823	4, 980	-------	¾	. 56	6. 35
4, 358	4, 723	4, 903	-------	5, 660	-------	-------	1½	. 55	6. 35
5, 290	4, 628	4, 155	-------	4, 916		-------	1½	. 55	6. 35
4, 295	3, 727	4, 751	-------	-------	3, 088	-------	¼	. 45	6. 23
3, 464	4, 728	4, 687	-------	-------	4, 971	-------	¼	. 45	6. 23
5, 365	5, 068	5, 568	-------	5, 810	5, 168	-------	¾	. 49	6. 23
Av. 3, 221	3, 675	3, 838	3, 552	4, 247	4, 012	3, 717	1. 18	. 578	-------

TABLE 25.—*Compressive strength of cylinders taken on Federal-aid project 163 in Canadian County, Okla.*

[Mix 1:2:3½; limestone coarse aggregate; Koehring mixer in fair condition]

(Pounds per square inch)

Mixing time in seconds							Slump (1-minute mix)	$\frac{W}{C}$	Fineness modulus
30	45	60	75	90	120	180			
							Inches		
3, 045	4, 495	5, 135	4, 415	4, 985	3, 260	4, 780	⅝–2¼	0. 56	6. 18
2, 580	4, 700	4, 845	4, 485	3, 405	3, 660	4, 130			
4, 325	4, 185	5, 350	5, 855	4, 520	3, 595	2, 420	11/16–5¼	. 56	6. 04
4, 630	4, 530	4, 920	5, 310	3, 730	4, 080	2, 650			
2, 261	3, 290	3, 820	4, 270	5, 160	3, 065	5, 240	½–4	. 58	6. 18
2, 030	3, 330	4, 052	4, 520	5, 255	2, 750	4, 625			
Av. 3, 145	4, 088	4, 687	4, 809	4, 509	3, 402	3, 974	-------	. 57	-------

Table 26 gives the modulus of rupture for a series of beams. The cylinders taken on this job are not reported as a new laboratory practice which was used in breaking them rendered the results of doubtful significance.

TABLE 26.—*Modulus of rupture of a series of beams taken on Federal-aid project 55A in Andersen County, Tenn. Each entry is the average of three breaks*

[Mix 1: 2: 3½; stone and gravel coarse aggregate; new Koehring mixer]

	Mixing time in seconds					
	45	60	75	120	180	240
Pounds per square inch	600	532	768	590	635	670
Do	498	505	501	677	660	-------
Do	591	524	489	530	-------	-------
Do	617	518	556	-------	-------	-------
Do	733	658	516	-------	-------	-------
Do	579	555	537	-------	-------	-------
Do	706	576	631	-------	-------	-------
Do	716	758	591	-------	-------	-------
Do	513	590	563	-------	-------	-------
Do	583	522	588	-------	-------	-------
Average	614	574	574	599	647	670
Total number of breaks	32	34	36	10	7	3
Maximum	733	758	768	677	-------	-------
Minimum	498	505	489	530	-------	-------
Difference	235	253	279	147	-------	-------
Difference, per cent	32	33	36	22	-------	-------

TABLE 27.—*Data on cylinders and beams secured on Federal-aid project 208C in Grady County, Okla. Specimens were cured by various methods*

[Mix 1: 2: 3½; limestone coarse aggregate: Koehring mixer in fair condition]

CURED WITH CALCIUM CHLORIDE—SURFACE APPLICATION OF 2 POUNDS PER SQUARE YARD

	30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams
	Inches		Lbs. per sq. in.	Lbs. per sq. in.	Inches		Lbs. per sq. in.	Lbs. per sq. in.	Inches		Lbs. per sq. sn.	Lbs. per sq. in.			Lbs. per sq. in.	Lbs. per sq. in.	Inches		Lbs. per sq. in.	Lbs. per sq. in.
					3.12	0.64	3,902	469	0.37	0.45	4,610		2.12	0.58	4,424	592				
					3.12	.64	4,136		.37	.45	4,375		2.12	.58	4,658					
					2.70	.60	3,525	664	.37	.45	4,620		2.00	.57	3,956	508				
					2.70	.60	4,496		.37	.45	4,175		2.00	.57	4,036					
					.25	.62	4,626	613	.37	.45	4,285		3.75	.45	3,823	514				
					.25	.62	4,379		.37	.45	4,136		3.75	.45	4,136					
					1.25	.56	3,600	582	1.50	.65	3,240	621	2.44	.64	3,465	533				
					1.25	.56	3,870		1.50	.65	3,130		2.44	.64	3,455					
					.32	.61	3,510	549	4.37	.67	3,095	550	2.00	.60	4,060	519				
					.32	.61	3,270		4.37	.67	3,240		2.00	.60	3,795					
									.75	.52	3,735									
									.75	.52	3,725									
											3,905									
											4,145									
											3,815									
											4,090									
Av.					1.53	.606	3,931	575	1.29	.533	3,895	585	2.46	.568	3,981	533				

CALCIUM CHLORIDE ADMIXTURE—2 PER CENT OF CEMENT BY WEIGHT

	30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams
	0.63	0.45	3,365	527	0.25	0.49	3,490	506	1.75	0.49	3,200	486	2.88	0.45	3,040	548	2.06	0.62	2,625	608
	.63	.45	3,380				2,985		1.75	.49	3,420				2,665	514	2.06	.62	2,305	435
	.88	.52	2,015	448	.37	.49	2,825	520	2.12	.54	2,550	478	.25	.50	2,875	576	.25	.68	2,825	530
	.88	.52	2,045		1.12	.52	2,535	479	2.12	.54	2,655		2.25	.54	2,265	413	.25	.68	3,290	
	.75	.49	4,110	575	1.12	.52	2,610		.63	.53	3,365	513	2.25	.54	2,610		2.50	.63	2,770	448
					1.00	.49	2,985	512	.63	.53	3,130		4.75	.52	2,430	565	2.50	.63	2,375	
					1.00	.49	3,345		2.12	.52	2,375	475	4.75	.52	2,590					
					1.12	.62	3,185	413	2.12	.52	2,335		.25	.58	3,435	458				
					1.12	.62	3,580		2.25	.50	2,225	542	.25	.58	3,625					
									2.25	.50	2,020	414								
Av.	0.76	.486	2,983	517	.88	.530	3,060	486	1.77	.516	2,728	485	2.20	.529	2,837	512	1.60	.643	2,698	505

CURED WITH MOIST EARTH

	30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams
					1.25	0.54	4,388	599	1.12	0.55	3,956	653	1.20	0.56	4,460	643				
					1.25	.54	3,462		1.12	.55	3,956		1.20	.56	4,763					
					3.37	.52	4,293	497	1.12	.55	3,600	626	5.12	.57	3,810	660				
					3.37	.52	4,172		1.12	.55	3,291		5.12	.57	3,525					
					.70	.51	4,270	553	1.12	.55	2,967		2.12	.54	3,878	711				
					.70	.51	4,496		1.12	.55	2,949		2.12	.54	3,705					
					.88	.49	4,352	649	3.12	.53	4,120		2.62	.51	4,442	604				
					.88	.49	4,388		3.12	.53	4,370		2.62	.51	4,028					
					2.75	.53	2,909	608	3.12	.49	3,992		2.25	.52	4,250	617				
					2.75	.53	4,448		3.12	.49	3,597		2.25	.52	3,471					
Av.					1.79	.518	4,118	581	1.92	.534	3,680	640	2.66	.540	4,033	647				

CURED IN OPEN AIR WITHOUT COVER OR SPRINKLING

	30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams
					2.37	0.58	3,200	493	0.50	0.50	3,235		1.70	0.54	3,420	565				
					2.37	.58	2,895		.50	.50	3,850		1.70	.54	3,215					
					1.00	.50	3,785	621	.50	.50	3,750		1.50	.56	3,920	493				
					1.00	.50	3,775		.50	.50	3,555		1.50	.56	3,295					
					.88	.54	3,510	529	.50	.50	3,865		1.25	.59	3,365	469				
					.88	.54	3,775		.50	.50	3,510		1.25	.59	2,855					
					1.50	.63	3,920	482	5.37	.58	2,335		2.88	.60	3,600	576				
					1.50	.63	4,190		5.37	.58	2,845		2.88	.60	2,600					
					1.25	.61	3,740	486	.58	.60	3,630	572	.88	.60	3,890	506				
					1.25	.61	3,810		.58	.60	3,750		.88	.60	3,955					
													3.50	.65		499				
Av.					1.40	.572	3,660	522	1.49	.536	3,433	572	1.81	.584	3,412	518				

Table 27 covers series of cylinders which were taken where special methods of curing were used on the pavement. The cylinders were cured just as the pavement was cured. Beams were also made (cross section 6 by 8 inches) and the modulus of rupture for these is given.

Table 28 gives the results of a series of density determinations of cylinders and cores with the breaking strengths of some of the cylinders. The uniformity of the densities determined for both cylinders and cores is outstanding but there is a wide variation in the breaking strength of the cylinders. The density determinations were made at the University of Texas under the direction of Professor Thomas, whose assistance in this and other phases of this study has been very helpful.

taken from each batch of concrete selected, and broken at ages of 10, 14, 21, and 28 days. There is no significant difference in the rate at which concrete mixed for various periods has increased in strength.

Tables 22 and 23 give data from jobs in South Carolina and in Kansas.

TABLE 22.—*Compressive strength of cylinders taken on Federal-aid project 243A, Spartanburg, S. C.*

[Mix 94:170:370 by weight; crushed stone coarse aggregate; Foote mixer in good condition; average slump one-half inch]

(In pounds per square inch)

45-second mix	60-second mix	75-second mix	45-second mix	60-second mix	75-second mix
3,490	3,050	2,990	2,715	3,395	3,395
3,165	2,780	2,950	3,790	3,780	3,510
3,850	3,610	3,770	2,890	3,195	3,550
3,010	3,090	3,590		2,895	3,245
3,730	3,985	3,950	3,090	3,675	3,795
3,290	3,310	2,990	3,655	3,475	3,240
3,110	3,390	3,330	3,390	3,250	3,810
3,450	3,375	2,995	3,770	3,215	4,180
3,335	3,415	4,000			
3,375	3,230	3,655	Av. 3,330	3,311	3,506
2,840	2,790	3,675			

TABLE 23.—*Data on cylinders taken on Federal-aid project 360A in Johnson County, Kans.*

[Mix 1:2:3½; limestone coarse aggregate; Foote mixer in fair condition]

45-second mix		60-second mix		90-second mix	
W/C	Compressive strength	W/C	Compressive strength	W/C	Compressive strength
	Lbs. per sq. in.		*Lbs. per sq. in.*		*Lbs. per sq. in.*
0.661	4,416	0.675	4,734	0.675	5,811
.661	4,522	.675	4,769	.675	4,875
.657	5,281	.669	4,928	.713	5,016
.657	5,246	.669	4,769	.713	4,981
.657	4,027	.669	5,145	.714	5,122
.657	4,946	.669	4,734	.714	4,486
.715	4,274	.666	5,122	.701	5,458
.715	3,674	.666	4,751	.701	5,476
.724	5,122	.661	5,511	.687	6,288
.724	4,928	.661	4,840	.687	6,112
.679	4,628	.668	5,158	.672	4,098
.679	4,204	.668	4,964	.672	3,921
.668	5,600	.675	5,511	.672	4,857
.668	4,946	.675	5,211	.672	4,159
.663	5,440	.684	5,370	.684	5,052
.663	3,833	.684	5,476	.684	4,963
.663	4,981	.684	5,087	.678	4,910
.663	4,416	.684	4,734	.678	4,910
.663	4,610	.684	4,487	.684	5,458
.663	3,939	.684	4,310	.684	5,450
.645	5,017	.652	5,547	.652	5,405
.645	5,599	.652	5,193	.652	5,052
.666	4,346	.652	5,900	.652	4,593
.666	3,674	.652	5,193	.652	4,204
.657	5,617	.654	6,006	.652	4,875
.657	4,767	.654	5,290	.652	4,346
.652	4,910	.654	6,289	.662	4,610
.652	4,593	.654	5,299	.662	3,992
.657	5,953	.654	6,112	.638	5,229
.657	5,600	.654	4,169	.638	5,087
Av. .668	4,770	.667	5,153	.676	4,960

Average for 15 cylinders	Compressive strength		
	45-second mix	60-second mix	90-second mix
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Cured with calcium chloride	4,580	4,920	4,800
Cured in damp earth	4,948	5,367	5,119

Tables 24 and 25 merely add to the data presented. Neither is of special significance.

TABLE 24.—*Compressive strength of cylinders taken on a job in Hillsdale County, Mich.*

[Mix 1:2:3.4; gravel coarse aggregate; Rex mixer in fair condition]

(Pounds per square inch)

Mixing time in seconds							Slump (1-minute mix)	W/C	Fineness modulus
30	45	60	75	90	120	180			
							Inches		
2,244	3,147	4,449	3,887	3,102	3,926	3,692	1¾	0.74	5.90
2,020	3,125	3,480	3,935	3,445	4,055	4,660	1¼	.68	5.60
2,780	2,550	2,965	3,210	2,871	2,859	3,380	------	.90	5.79
3,595	3,140	2,835	2,770	3,419	2,845	2,815	------	.80	5.76
3,000	3,720	3,440	3,960	3,680	4,285	4,040	------	.70	5.82
3,295	3,425	4,795	------	------	4,880	------	2	.58	5.88
2,900	3,880	4,530	------	------	4,625	------	1½	.50	5.88
2,800	4,090	3,840	------	------	4,670	------	1½	.50	5.88
2,711	2,409	2,642	------	------	2,622	------	1	.49	5.78
3,307	4,450	3,238	------	------	3,675	------	1	.49	5.78
1,657	2,687	4,000	------	4,000	3,678	------	1¾	.54	5.78
3,095	4,085	3,270	------	------	3,642	------	1¼	.52	5.77
2,580	3,420	2,700	------	------	3,710	------	1¼	.52	5.77
2,870	4,100	3,170	------	5,000	4,545	------	¾	.56	5.80
2,794	2,408	3,355	------	4,823	4,980	------	¾	.56	6.35
4,358	4,723	4,903	------	5,660	------	------	1½	.55	6.35
5,290	4,628	4,155	------	4,916	------	------	1½	.55	6.35
4,295	3,727	4,751	------	------	3,088	------	¼	.45	6.23
3,464	4,728	4,687	------	------	4,971	------	¼	.45	6.23
5,365	5,068	5,568	------	5,810	5,168	------	¾	.49	6.23
Av. 3,221	3,675	3,838	3,552	4,247	4,012	3,717	1.18	.578	------

TABLE 25.—*Compressive strength of cylinders taken on Federal-aid project 163 in Canadian County, Okla.*

[Mix 1:2:3½; limestone coarse aggregate; Koehring mixer in fair condition]

(Pounds per square inch)

Mixing time in seconds							Slump (1-minute mix)	W/C	Fineness modulus
30	45	60	75	90	120	180			
							Inches		
3,045	4,495	5,135	4,415	4,985	3,260	4,780	⅝–2¼	0.56	6.18
2,580	4,700	4,845	4,485	3,405	3,660	4,130			
4,325	4,185	5,350	5,855	4,520	3,595	2,420	1⅛–5¼	.56	6.04
4,630	4,530	4,920	5,310	3,730	4,080	2,650			
2,261	3,290	3,820	4,270	5,160	3,065	5,240	½–4	.58	6.18
2,030	3,330	4,052	4,520	5,255	2,750	4,625			
Av. 3,145	4,088	4,687	4,809	4,509	3,402	3,974	------	.57	------

Table 26 gives the modulus of rupture for a series of beams. The cylinders taken on this job are not reported as a new laboratory practice which was used in breaking them rendered the results of doubtful significance.

TABLE 26.—*Modulus of rupture of a series of beams taken on Federal-aid project 55A in Anderson County, Tenn. Each entry is the average of three breaks*

[Mix 1:2:3½; stone and gravel coarse aggregate; new Koehring mixer]

	Mixing time in seconds					
	45	60	75	120	180	240
Pounds per square inch	600	532	768	590	635	670
Do	498	505	501	677	660	------
Do	591	524	489	530	------	------
Do	617	518	556	------	------	------
Do	733	658	516	------	------	------
Do	579	555	537	------	------	------
Do	706	576	631	------	------	------
Do	716	758	591	------	------	------
Do	513	590	563	------	------	------
Do	583	522	588	------	------	------
Average	614	574	574	599	647	670
Total number of breaks	32	34	36	10	7	3
Maximum	733	758	768	677	------	------
Minimum	498	505	489	530	------	------
Difference	235	253	279	147	------	------
Difference, per cent	32	33	36	22	------	------

TABLE 27.—*Data on cylinders and beams secured on Federal-aid project 208C in Grady County, Okla. Specimens were cured by various methods*

[Mix 1: 2: 3½; limestone coarse aggregate: Koehring mixer in fair condition]

30-second mix				45-second mix				60-second mix				90-second mix				180-second mix			
Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams	Slump	W/C	Compressive strength of cylinders	Modulus of rupture of beams
Inches		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*			*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches*		*Lbs. per sq. in.*	*Lbs. per sq. in.*
CURED WITH CALCIUM CHLORIDE—SURFACE APPLICATION OF 2 POUNDS PER SQUARE YARD																			
				3.12	0.64	3,902	469	0.37	0.45	4,610		2.12	0.58	4,424	592				
				3.12	.64	4,136		.37	.45	4,375		2.12	.58	4,658					
				2.70	.60	3,525	664	.37	.45	4,620		2.00	.57	3,956	508				
				2.70	.60	4,496		.37	.45	4,175		2.00	.57	4,036					
				.25	.62	4,626	613	.37	.45	4,285		3.75	.45	3,823	514				
				.25	.62	4,379		.37	.45	4,136		3.75	.45	4,136					
				1.25	.56	3,600	582	1.50	.65	3,240	621	2.44	.64	3,465	533				
				1.25	.56	3,870		1.50	.65	3,130		2.44	.64	3,455					
				.32	.61	3,510	549	4.37	.67	3,095	550	2.00	.60	4,060	519				
				.32	.61	3,27[illegible]		4.37	.67	3,240		2.00	.60	3,795					
								.75	.52	3,735									
								.75	.52	3,725									
										3,905									
										4,145									
										3,815									
										4,090									
Av.				1.53	.606	3,931	575	1.29	.533	3,895	585	2.46	.568	3,981	533				
CALCIUM CHLORIDE ADMIXTURE—2 PER CENT OF CEMENT BY WEIGHT																			
0.63	0.45	3,365	527	0.25	0.49	3,490	506	1.75	0.49	3,200	486	2.88	0.45	3,040	548	2.06	0.62	2,625	608
.63	.45	3,380				2,985		1.75	.49	3,420				2,665	514	2.06	.62	2,305	435
.88	.52	2,015	448	.37	.49	2,825	520	2.12	.54	2,550	478	.25	.50	2,875	576	.25	.68	2,825	530
.88	.52	2,045		1.12	.52	2,535	479	2.12	.54	2,655		2.25	.54	2,265	413	.25	.68	3,290	
.75	.49	4,110	575	1.12	.52	2,610		.63	.53	3,365	513	2.25	.54	2,610		2.50	.63	2,770	448
				1.00	.49	2,985	512	.63	.53	3,130		4.75	.52	2,430	565	2.50	.63	2,375	
				1.00	.49	3,345		2.12	.52	2,375	475	4.75	.52	2,590					
				1.12	.62	3,185	413	2.12	.52	2,335		.25	.58	3,435	458				
				1.12	.62	3,580		2.25	.50	2,225	542	.25	.58	3,625					
								2.25	.50	2,020	414								
Av. 0.76	.486	2,983	517	.88	.530	3,060	486	1.77	.516	2,728	485	2.20	.529	2,837	512	1.60	.643	2,698	505
CURED WITH MOIST EARTH																			
				1.25	0.54	4,388	599	1.12	0.55	3,956	653	1.20	0.56	4,460	643				
				1.25	.54	3,462		1.12	.55	3,956		1.20	.56	4,763					
				3.37	.52	4,293	497	1.12	.55	3,600	626	5.12	.57	3,810	660				
				3.37	.52	4,172		1.12	.55	3,291		5.12	.57	3,525					
				.70	.51	4,270	553	1.12	.55	2,967		2.12	.54	3,878	711				
				.70	.51	4,496		1.12	.55	2,949		2.12	.54	3,705					
				.88	.49	4,352	649	3.12	.53	4,120		2.62	.51	4,442	604				
				.88	.49	4,388		3.12	.53	4,370		2.62	.51	4,028					
				2.75	.53	2,909	608	3.12	.49	3,992		2.25	.52	4,250	617				
				2.75	.53	4,448		3.12	.49	3,597		2.25	.52	3,471					
Av.				1.79	.518	4,118	581	1.92	.534	3,680	640	2.66	.540	4,033	647				
CURED IN OPEN AIR WITHOUT COVER OR SPRINKLING																			
				2.37	0.58	3,200	493	0.50	0.50	3,235		1.70	0.54	3,420	565				
				2.37	.58	2,895		.50	.50	3,850		1.70	.54	3,215					
				1.00	.50	3,785	621	.50	.50	3,750		1.50	.56	3,920	493				
				1.00	.50	3,775		.50	.50	3,555		1.50	.56	3,295					
				.88	.54	3,510	529	.50	.50	3,865		1.25	.59	3,365	469				
				.88	.54	3,775		.50	.50	3,510		1.25	.59	2,855					
				1.50	.63	3,920	482	5.37	.58	2,335		2.88	.60	3,600	576				
				1.50	.63	4,190		5.37	.58	2,845		2.88	.60	2,600					
				1.25	.61	3,740	486	.58	.60	3,630	572	.88	.60	3,890	506				
				1.25	.61	3,810		.58	.60	3,750		.88	.60	3,955					
												3.50	.65		499				
Av.				1.40	.572	3,660	522	1.49	.536	3,433	572	1.81	.584	3,412	518				

Table 27 covers series of cylinders which were taken where special methods of curing were used on the pavement. The cylinders were cured just as the pavement was cured. Beams were also made (cross section 6 by 8 inches) and the modulus of rupture for these is given.

Table 28 gives the results of a series of density determinations of cylinders and cores with the breaking strengths of some of the cylinders. The uniformity of the densities determined for both cylinders and cores is outstanding but there is a wide variation in the breaking strength of the cylinders. The density determinations were made at the University of Texas under the direction of Professor Thomas, whose assistance in this and other phases of this study has been very helpful.

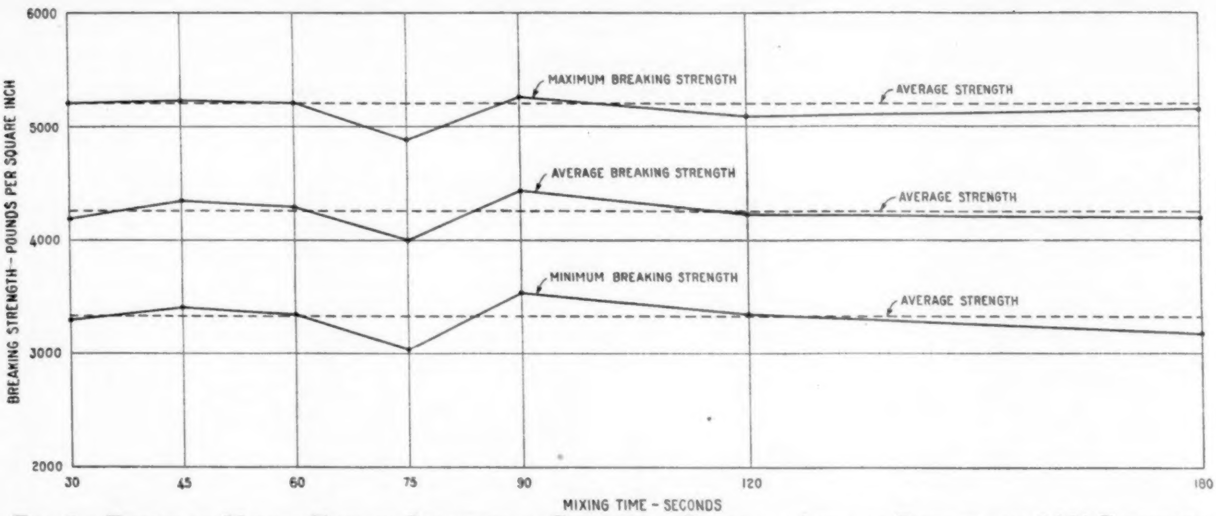


FIG. 1.—EFFECT OF MIXING TIME ON STRENGTH OF CONCRETE. BASED ON AVERAGE RESULTS FOR 1,266 CYLINDERS FROM 24 JOBS. BROKEN LINE SHOWS AVERAGE BREAKING STRENGTH OF EACH GROUP WITHOUT REGARD TO MIXING TIME

TABLE 28.—*Results of density determinations of cylinders and cores taken on Federal-aid project 449A in Clay County, Tex.*

[Mix 1:2:3½; crushed rock and gravel coarse aggregate; Koehring mixer in good condition]

DETERMINATIONS FOR CYLINDERS

Density	Mixing time	Compressive strength	Density	Mixing time	Compressive strength
	Seconds	*Lbs. per sq. inch*		*Seconds*	*Lbs. per sq. inch*
2.411			2.406	30	4,200
2.443			2.409	120	5,600
2.428			2.409	45	5,370
2.422			2.402	60	6,050
2.436			2.436	90	4,540
2.415			2.448	30	7,470
2.438			2.456	30	7,770
2.425			2.441	30	6,320
2.424	60	4,906	2.443		
2.408	120	4,470	2.443		
2.431	90	5,230			
2.418	45	4,750	Av. 2.429		

DETERMINATIONS FOR CORES

2.40			2.47		
2.50					
2.47			Av. 2.460		

Table 29 is a general summary of the preceding tables. In preparing this table the results secured on Texas Federal-aid project 475 and Oklahoma State-aid project 159A have been omitted because in one case the mixer charged slowly and in the other case the inside of the drum was heavily coated with concrete. Kansas Federal-aid project 360A might, with some reason, also have been omitted as the mixer charged slowly, though in this case the lag was not extreme. These results cause a slight reduction in the average strength of the concrete mixed 45 seconds.

Table 30 is a study of the uniformity of the test results. It is valuable in that it brings out the fact that uniformity of results has not been greatly affected by the length of the mixing period.

Before presenting the conclusions drawn from this study, it is desired to refer to work along this same line done by the California State Highway Department and reported by S. S. Pope in California Highways, February, 1926. These tests resulted in the conclusion that concrete mixed two minutes was not better than that mixed one minute.

Reference should also be made to the report of Duff A. Abrams before the 1918 meeting of the American Concrete Institute. It appears from a rather careful study of the data presented at that time that a fact of considerable importance has been overlooked in this report, and in discussions of it, namely, that for mixes of approximately the proportions now used in concrete paving and for water-cement ratios approximately as are in use to-day, increasing the mixing period from one minute to two minutes not only failed to increase strength but actually caused an average loss in strength.

Every investigator should be permitted all reasonable latitude in the interpretation of the results of tests made under his direction. Therefore, as a recession in a generally ascending curve such as the mixing-time-strength curve has been assumed to be, is of uncommon occurrence, it is not surprising that in plotting the results of this test the significance of these results was overlooked, a steadily rising curve being used. But, in view of the data which has been secured, it is interesting to wonder whether the test results were not, after all, accurate and the interpretations of them on which modern practice in this matter so largely rests, too general. Figure 1 and Table 29 summarize the data secured in the mixing-time studies for the convenience of those who wish to examine the general trends indicated.

CONCLUSIONS

Conclusions drawn from an investigation of this sort must be prefaced by at least a brief reference to such matters as the margin of error in testing work, of the meaning of averages, of probabilities and related matters. For example, it is known that the results obtained by breaking a long series of cylinders, which are as nearly alike as anyone knows how to make them, are seldom wholly consistent. How much of this is due to differences in the cylinders themselves, no one knows. It is customary to assume that much, if not most of it, is. On the other hand, the average strengths obtained by different laboratories on groups of random cylinders taken from a series, all of which should be of equal strength, will sometimes differ more than a thousand pounds. This is quite a sufficient basis for the conclusion that differences in the strength of individual cylinders in the same series are not wholly the result of differences in the cylinders themselves.

TABLE 29.—*General summary of data secured on cylinders*

State and project No.	Type of curing	Mixer: Make	Mixer: Site	Mixer: Condition	Drum speed (revolutions per minute)	Charging lag	Mix	Kind of aggregate	30-second mix: Cylinders	30-second mix: Slump	30-second mix: Av. $\frac{W}{C}$	30-second mix: Average compressive strength	30-second mix: Maximum compressive strength	30-second mix: Minimum compressive strength	30-second mix: Variation from general average
						Secs.			*Number*	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*
Texas, F. A. P. 136X	Earth	Koehring	21-E	Good	17	5	1:2:3.4	Gravel	7	1.25	0.663	5,641	6,220	5,000	−4.2
Texas, F. A. P. 479	do	Ransome	do	New	17	6	1:2:3.5	do	10	1.17	.470	4,158	5,200	3,070	−1.3
Texas, F. A. P. 475	do	Foote	do	Poor	14	9	1:2:3.5	do							
Okla., F. A. P. 159A	do	Koehring	do	Good	17.5	5	1:3:3.5	do	10	.81	.577	4,990	5,400	4,740	−1.1
Okla., S. A. P. 318	do	Rex	do	Poor	14.75	6	1:2:3.5	do	[1] 9	2.25	.607	3,499	4,200	2,970	−20.8
Okla., F. A. P. 130	do	Smith	do	Good	15	5	1:2:3.5	Limestone	6	.57	.693	4,642	5,215	4,270	−1.7
Mo., F. A. P. 229C	CaCl	Koehring	27-E	do	15	7	1:2.5:3.5	do	5	1.75	.700	3,172	3,540	2,500	−14.0
Texas, F. A. P. 448B	Earth	do	do	do	18	5	1:2:3.5	Gravel	5			5,092	5,520	4,660	+8.1
Mich., Job No. 1	do	do	21-E	Fair	17	6	1:2:3.4	do	16	.85	.558	3,707	4,910	2,675	−6.8
Okla., F. A. P. 148E	do	Rex	do	Good	16	4	1:2:3.5	Limestone							
Do	No-curing	do	do	do	16	4	1:2:3.5	do							
Do	CaCl admixture	do	do	do	16	4	1:2.3.5	do	5	2.98	.574	3,678	4,650	2,382	−18.4
Do	CaCl	do	do	do	16	4	1:2:3.5	do							
Texas, F. A. P. 449A	Earth	Koehring	do	do	16.5	5	1:2:3.5	Stone and gravel	20	2.44	.546	5,464	7,770	3,900	+5.4
S. C., S. A. P. 507	do	do	27-E	New	16.5	12	1:2:3.5	Stone							
Okla., F. A. P. 174B2	do	do	21-E	Good	17	5	1:2:3.5	Gravel	10		.650	4,344	4,990	3,230	−1.3
Okla., F.A.P. 174B2, F.A.P. 188A	do	do	do	do	17	5	1:2:3.5	do							
S. C., F. A. P. 243A	do	Foote	27-E	do	15	10	1:2:3.5	Stone							
Kansas, F. A. P. 360A	do	do	do	Fair	15	14	1:2:3.5	Limestone							
Do	CaCl	do	do	do	15	14	1:2:3.5	do							
Okla., F. A. P. 208C	do	Koehring	21-E	do	15	5	1:2:3.5	do							
Do	CaCl admixture	do	do	do	15	5	1:2:3.5	do	5	.76	.486	2,983	4,110	2,015	+4.3
Do	Earth	do	do	do	15	5	1:2:3.5	do							
Do	No-curing	do	do	do	15	5	1:2:3.5	do							
Mich., Job No. 2	Earth	Rex	do	do	14	5	1:2:3.4	Gravel	19	1.18	.578	3,221	5,365	1,657	−14.2
Okla., F. A. P. 163	do	Koehring	do	do	16	5	1:2:3.5	Stone and gravel	6		.567	3,145	4,630	2,030	−23.1
Total or average [1]									124			4,172	5,194	3,241	−1.8

State and project No.	45-second mix: Cylinders	45-second mix: Slump	45-second mix: Av. $\frac{W}{C}$	45-second mix: Average compressive strength	45-second mix: Maximum compressive strength	45-second mix: Minimum compressive strength	45-second mix: Variation from general average	60-second mix: Cylinders	60-second mix: Slump	60-second mix: Av. $\frac{W}{C}$	60-second mix: Average compressive strength	60-second mix: Maximum compressive strength	60-second mix: Minimum compressive strength	60-second mix: Variation from general average
	Number	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*	*Number*	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*
Texas, F. A. P. 136X	9	1.25	0.639	6,172	6,820	5,470	+4.8	18	1.54	0.645	5,867	6,980	4,750	−0.4
Texas, F. A. P. 479	10	1.62	.610	4,481	5,010	4,010	+6.4	9	1.72	.467	4,090	4,950	3,440	−2.9
Texas, F. A. P. 475	[1] 6	1.25	.600	4,822	5,330	4,210	−2.0	[1] 6	2.75	.640	4,727	5,610	3,100	−3.9
Okla., F. A. P. 159A	9	.75	.588	5,123	6,300	4,270	−1.6	10	1.49	.626	4,902	5,980	3,630	−2.8
Okla., S. A. P. 318	[1] 7	1.75	.609	3,670	4,880	2,405	−17.0	[1] 7	1.27	.631	4,576	5,020	4,010	+3.5
Okla., F. A. P. 130	6	.65	.693	4,802	5,650	4,320	+1.7	6	.98	.697	4,790	5,320	4,235	+1.4
Mo., F. A. P. 229C	25	1.50	.700	3,773	4,909	3,040	+2.3	19	1.70	.710	3,817	4,818	2,760	+3.5
Texas, F. A. P. 448B	12		.600	4,948	5,810	3,910	+5.0	13		.590	4,651	5,720	3,520	−1.3
Mich., Job No. 1	18	.85	.558	4,073	5,800	2,980	+2.4	18	.85	.558	4,204	5,220	2,800	+5.7
Okla., F. A. P. 148E	10	1.04	.604	3,820	4,960	2,480	−4.7	10	1.08	.604	3,892	5,030	2,490	−2.9
Do	10	1.23	.542	4,659	5,685	3,450	−6.2	10	.95	.542	5,251	6,040	4,635	−5.9
Do	10	1.50	.574	4,264	5,465	2,706	−5.5	10	1.34	.574	4,720	5,215	4,070	+4.6
Do	10	.85	.556	3,829	4,460	3,160	+2.2	10	.97	.556	3,580	4,280	2,660	−4.5
Texas, F. A. P. 449A	20	2.94	.625	5,310	6,400	4,400	+2.4	53	2.43	.592	5,168	7,220	3,580	−.3
S. C., S. A. P. 507								76		.627	3,084	4,960	1,500	+3.8
Okla., F. A. P. 174B2	10		.644	4,399	5,220	3,450	−.1	10		.660	4,440	5,350	3,470	+.9
Okla., F. A. P. 174B2, F. A. P. 188A	13	1.50	.640	4,935	5,630	3,710	−1.0	26	1.70	.650	5,034	5,820	3,750	+1.0
S. C., F. A. P. 243A	18			3,330	3,850	2,715	−1.5	19			3,311	3,985	2,780	−2.1
Kansas, F. A. P. 360A	15		.668	4,948	5,953	4,027	−3.8	15		.667	5,367	6,289	4,487	+4.3
Do	15		.668	4,580	5,600	3,674	−3.9	15		.667	4,920	5,476	4,169	+3.2
Okla., F. A. P. 208C	10	1.53	.606	3,931	4,626	3,270	−.1	16	1.29	.533	3,895	4,620	3,095	−1.0
Do	9	.88	.530	3,060	3,580	2,535	+7.0	10	1.77	.516	2,728	3,420	2,020	−4.7
Do	10	1.79	.518	4,118	4,496	2,909	+4.4	10	1.92	.534	3,680	4,370	2,949	−6.7
Do	10	1.40	.572	3,660	4,190	2,895	+4.5	10	1.49	.536	3,433	3,865	2,335	−2.0
Mich., Job No. 2	20	1.18	.578	3,675	5,068	2,408	−2.1	20	1.18	.578	3,838	5,568	2,642	+2.3
Okla., F. A. P. 163	6		.567	4,088	4,700	3,290	−.1	6		.567	4,687	5,350	3,820	+14.6
Total or average [1]	286			4,347	5,225	3,438	+2.3	419			4,306	5,244	3,316	+1.4

[1] Data secured on Texas Federal-aid project 475 and Oklahoma State-aid project 318 not included in totals and averages for reasons explained in text.

TABLE 29.—*General summary of data secured on cylinders*—Continued

State and project No.	75-second mix: Cylinders	75-second mix: Slump	75-second mix: Av. $\frac{W}{C}$	75-second mix: Average compressive strength	75-second mix: Maximum compressive strength	75-second mix: Minimum compressive strength	75-second mix: Variation from general average	90-second mix: Cylinders	90-second mix: Slump	90-second mix: Av. $\frac{W}{C}$	90-second mix: Average compressive strength	90-second mix: Maximum compressive strength	90-second mix: Minimum compressive strength	90-second mix: Variation from general average
	Number	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*	*Number*	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*
Texas, F. A. P. 136X								9	1.39	0.626	6,118	6,565	5,520	+3.9
Texas, F. A. P. 479								10	2.20	.582	4,477	4,920	3,860	+6.3
Texas, F. A. P. 475	[1]4	1.88	0.630	4,752	5,250	4,230	−3.4	[1]6	3.42	.650	4,970	5,560	4,520	+1.0
Okla., F. A. P. 159A	10	1.66	.632	5,194	5,720	4,270	+3.0	10	1.26	.615	4,953	5,840	4,160	−1.8
Okla., S. A. P. 318	[1]7	1.53	.616	5,009	6,100	4,076	+13.3	[1]8	1.48	.593	4,623	5,625	3,274	+4.5
Okla., F. A. P. 130	4	1.02	.700	4,746	5,320	4,010	+.5	6	.98	.693	4,476	4,845	3,918	−5.2
Mo., F. A. P. 229C	14	2.00	.700	3,857	4,780	2,870	+4.6	3		650	4,283	4,430	4,200	+16.1
Texas, F. A. P. 448B								5		.600	4,558	5,220	3,410	−3.2
Mich., Job No. 1	10	.85	.558	3,678	5,270	2,227	−7.5	10	.85	.558	3,853	5,240	2,530	−3.1
Okla., F. A. P. 148E								10	1.15	.604	4,311	5,870	2,590	+7.6
Do								10	1.30	.542	4,988	5,460	4,250	+.4
Do								10	1.49	.574	4,768	5,785	4,215	+5.7
Do								10	1.43	.556	3,835	4,245	3,000	+2.3
Texas, F. A. P. 449A								10	2.90	.599	5,001	6,950	4,070	−3.5
S. C., S. A. P. 507	79		.634	3,017	4,760	1,420	+1.6	27		.626	3,017	3,950	2,060	+1.6
Okla., F. A. P. 174B2								10		.630	4,429	5,200	3,800	+.6
Okla., F. A. P. 174B2, F. A. P. 188A								13		.640	4,983	6,250	3,230	0
S. C., F. A. P. 243A	19			3,506	4,180	2,950	+3.7							
Kansas, F. A. P. 360A								15		.679	5,119	6,288	4,098	−.5
Do								15		679	4,800	6,112	3,921	+.7
Okla., F. A. P. 208C								10	2.46	.568	3,981	4,658	3,455	+1.1
Do								9	2.20	.529	2,837	3,625	2,265	−.8
Do								10	2.66	.540	4,033	4,763	3,471	+2.3
Do								10	1.64	.578	3,412	3,955	2,600	−2.6
Mich., Job No. 2	5	1.18	.578	3,552	3,960	2,770	−5.3	11	1.18	.578	4,247	5,810	2,871	+13.2
Okla., F. A. P. 163	6		.567	4,827	5,855	4,270	+18.0	6		.567	4,509	5,255	3,405	+10.2
Total or average [1]	147			4,047	4,981	3,098	−4.7	239			4,391	5,271	3,517	+3.4

State and project No.	120-second mix: Cylinders	120-second mix: Slump	120-second mix: Av. $\frac{W}{C}$	120-second mix: Average compressive strength	120-second mix: Maximum compressive strength	120-second mix: Minimum compressive strength	120-second mix: Variation from general average	180-second mix: Cylinders	180-second mix: Slump	180-second mix: Av. $\frac{W}{C}$	180-second mix: Average compressive strength	180-second mix: Maximum compressive strength	180-second mix: Minimum compressive strength	180-second mix: Variation from general average	General average strength of mixes	Total cylinders
	Number	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*	*Number*	*Inches*		*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Per cent*	*Pounds per sq. in.*	*Number*
Texas, F. A. P. 136X	9	1.36	0.618	5,168	6,550	4,015	−12.5	7	1.94	0.680	6,378	6,930	5,570	+8.3	5,891	59
Texas, F. A. P. 479	8	1.34	.506	3,851	4,850	3,090	−8.6								4,211	47
Texas, F. A. P. 475	[1]6	3.17		5,000	5,490	4,560	+1.6	[1]4	2.00		5,248	5,460	5,110	+6.9	4,920	32
Okla., F. A. P. 159A	10	1.54	.595	5,100	5,650	4,060	+1.1								5,044	59
Okla., S. A. P. 318	[1]7	1.89	.632	4,942	5,840	4,529	+11.5	[1]2	1.75	.680	4,635	4,635	4,635	+4.8	4,422	47
Okla., F. A. P. 130	5	1.00	.692	5,054	5,855	4,600	+7.0	4	.96	.692	4,542	5,225	4,065	−3.8	4,722	37
Mo., F. A. P. 229C	5			3,670	4,190	3,182	−.5	3			3,243	4,670	1,940	−12.1	3,688	74
Texas, F. A. P. 448B	5			4,302	4,700	3,850	−8.7								4,710	40
Mich., Job No. 1	17	.85	.558	4,111	5,780	2,780	+3.3	9		558	4,222	5,350	2,900	+6.1	3,978	98
Okla., F. A. P. 148E															4,008	30
Do															4,966	30
Do								5	1.12	.574	5,123	5,745	4,855	+13.5	4,511	40
Do															3,748	30
Texas, F. A. P. 449A	10	2.35	.580	4,978	5,920	4,210	−4.0								5,184	113
S. C., S. A. P. 507	23		.637	2,762	3,460	2,100	−7.0								2,970	205
Okla., F. A. P. 174B2	10		.638	4,394	5,160	3,350	−.2								4,401	50
Okla., F. A. P. 174B2, F. A. P. 188A															4,984	52
S. C., F. A. P. 243A															3,382	56
Kansas, F. A. P. 360A															5,145	45
Do															4,767	45
Okla., F. A. P. 208C															3,936	36
Do								6	1.60	.643	2,698	3,290	2,305	−5.7	2,861	39
Do															3,944	30
Do															3,502	30
Mich., Job No. 2	18	1.18	.578	4,012	5,168	2,622	+6.8	5	1.18	.578	3,717	4,660	2,815	−.9	3,752	98
Okla., F. A. P. 163	6		.567	3,402	4,080	2,750	−16.9	6		.567	3,774	5,240	2,420	−2.8	4,090	42
Total or average [1]	126			4,233	5,114	3,384	−.4	45			4,237	5,139	3,359		4,248	1,385

[1] Data secured on Texas Federal-aid project 475 and Oklahoma State-aid project 318 not included in totals and averages for reasons explained in text.

This is brought out in Table 28, the differences in strength in this case being so much greater than the difference in specific gravity that it seems some other factor must be involved.

The unavoidable errors innate in work of this sort make it impossible to assert that we are ever dealing with specific facts. What we really have is a mass of data, all of which may be inexact and most of which undoubtedly is somewhat in error. Averages tend to correct these errors, but do not wipe them out entirely. The averages certainly are not accurate as to the units or the tens, and probably are not accurate as to the hundreds. Indeed, it is doubtful if they are accurate to within 5 per cent. This being the case, their significance lies in the trend they show. For this study the averages secured for mixing periods from 45 seconds to 180 seconds, when plotted, produce a saw-toothed effect without significant trend either up or down. The figures themselves are practically meaningless, but the lack of either upward or downward trend is significant. It is also significant that there is the same lack of trend in the average maximum and in the average minimum strengths. The amount of data accumulated on core strengths and on beam strengths is less than that accumulated on cylinder strengths, but none of it in any way is contradictory to the data derived from cylinders.

Summarizing the situation in the light of the data collected during this study, the evidence strongly indicates that where standard 21E and 27E pavers which are in good condition are used, neither strength nor uniformity of test results is improved by mixing the concrete over 45 seconds.

TABLE 30.—*Uniformity of test results as indicated by percentage of cylinders varying in compressive strength by 15, 10, and 5 per cent from average for group*

[A total of 1,464 cylinders reported in this tabulation, but only 1,385 included in averages]

State and project No.	30-second mix				45-second mix				60-second mix				75-second mix			
	Cylinders	15 per cent	10 per cent	5 per cent	Cylinders	15 per cent	10 per cent	5 per cent	Cylinders	15 per cent	10 per cent	5 per cent	Cylinders	15 per cent	10 per cent	5 per cent
	Number				*Number*				*Number*				*Number*			
Tex., F. A. P. 136X	7	0	29	29	9	11	22	67	18	11	22	61				
Tex., F. A. P. 479	10	50	60	90	10	0	20	40	9	33	67	78				
Tex., F. A. P. 475					6	0	[1]33	[1]50	6	[1]67	[1]67	100	4	0	[1]50	[1]100
Okla., F. A. P. 159A	10	0	0	20	9	22	44	67	10	20	30	60	10	10	20	90
Okla., S. A. P. 318	9	[1]33	[1]67	[1]78	7	[1]86	[1]86	[1]86	7	0	[1]29	[1]57	7	[1]43	[1]43	[1]86
Okla., F. A. P. 130	6	0	17	50	6	17	17	50	6	0	33	67	4	25	50	50
Mo., F. A. P. 229C	5	20	60	80	25	20	48	76	19	32	63	84	14	21	43	71
Tex., F. A. P. 448B	5	0	0	40	12	25	42	58	13	31	38	69				
Mich., job 1	16	38	50	75	18	50	61	84	18	56	72	89	10	50	80	100
Okla., F. A. P. 148E					10	50	60	90	10	60	80	90				
Do.					10	50	80	80	10	0	30	60				
Do.	5	100	100	100	10	40	60	70	10	0	20	70				
Do.					10	30	70	80	10	50	50	60				
Tex., F. A. P. 449A	20	70	80	85	20	20	25	70	53	32	51	75				
S. C., S. A. P. 507									76	45	59	83	79	25	46	71
Okla., F. A. P. 174B2	10	0	30	60	10	20	40	80	10	30	40	70				
Okla., F. A. P. 174B2, 188A					13	8	54	77	26	12	42	65				
S. C., F. A. P. 243A					18	11	39	56	19	16	37	47	19	11	32	68
Kans., F. A. P. 360A					15	7	47	80	15	13	33	53				
Do.					15	33	47	73	15	7	20	53				
Okla., F. A. P. 208C					10	20	50	80	16	38	44	69				
Do.	5	60	100	100	9	22	33	67	10	50	80	90				
Do.					10	20	20	60	10	30	50	80				
Do.					10	10	30	40	10	20	40	70				
Mich., job 2	19	47	74	89	20	45	75	90	20	60	75	85	5	20	60	100
Okla., F. A. P. 163	6	33	67	83	6	33	50	83	6	17	50	67	6	17	33	100
Total or average	124	32	51	69	285	25	45	70	419	28	47	71	147	22	46	81

State and project No.	90-second mix				120-second mix				180-second mix			
	Cylinders	15 per cent	10 per cent	5 per cent	Cylinders	15 per cent	10 per cent	5 per cent	Cylinders	15 per cent	10 per cent	5 per cent
	Number				*Number*				*Number*			
Tex., F. A. P. 136X	9	0	0	33	9	56	67	100	7	0	14	43
Tex., F. A. P. 479	10	0	20	60	8	38	63	75				
Tex., F. A. P. 475	6	0	[1]17	[1]33	6	0	0	[1]50	4	0	0	0
Okla., F. A. P. 159A	10	30	60	70	10	10	20	40				
Okla., S. A. P. 318	8	[1]25	[1]25	[1]62	7	[1]14	[1]14	[1]57	2	0	0	0
Okla., F. A. P. 130	6	0	17	33	5	20	20	60	4	25	50	50
Mo., F. A. P. 229C	3	0	0	0	5	40	60	80	3	67	67	67
Tex., F. A. P. 448B	5	20	40	80	5	0	40	40				
Mich., job 1	10	50	50	70	17	47	71	82	9	67	67	78
Okla., F. A. P. 148E	10	50	60	70								
Do.	10	0	10	70								
Do.	10	10	30	40					5	0	20	40
Do.	10	10	30	80								
Tex., F. A. P. 449A	10	30	40	70	10	30	60	60				
S. C., S. A. P. 507	27	15	37	59	23	26	43	78				
Okla., F. A. P. 174B2	10	10	40	70	10	20	50	70				
Okla., F. A. P. 174B2, 188A	13	31	46	54								
Kans., F. A. P. 360A	15	13	27	60								
Do.	15	13	47	73								
Okla., F. A. P. 208C	10	10	40	40								
Do.	9	22	33	56					6	17	50	50
Do.	10	10	50	70								
Do.	10	20	50	70								
Mich., job 2	11	73	82	100	18	56	78	89	5	40	40	80
Okla., F. A. P. 163	6	50	83	83	6	17	33	67	6	83	83	83
Total or average	239	20	39	61	126	30	50	70	45	37	49	61

[1] Not included in totals or averages (79 cylinders).

LIP CURB FOR CONCRETE PAVEMENT

Reported by ST. CLAIR T. THOMAS, Associate Highway Engineer, Division of Design, United States Bureau of Public Roads

LIP curbs, to protect the earth shoulders of concrete pavements from erosion by the run-off of rain water, have been included in designs submitted for Federal-aid projects, by four States—Georgia, Illinois, Iowa, and Minnesota. These designs are shown in Figure 1. The lip curb, or edging, constructed on the top of the pavement, serves the purpose of carrying the rain water to the nearest offtake. It differs from the integral curb, or the curb and gutter, as its capacity is only sufficient for normal rainfalls, and the height—2 to 3 inches in 8 to 12 inches—is not sufficient to prevent traffic from running over the edge of the pavement.

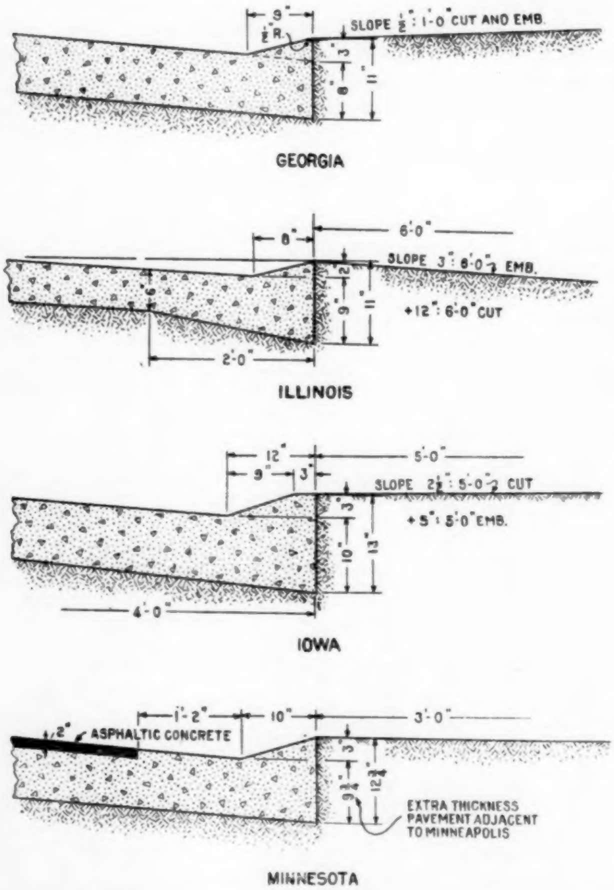


Fig. 1.—Designs of Lip Curbs for Concrete Pavements

The necessity for lip curb is determined by the character of the shoulder material and the grade of the pavement. It is usually not required in the heavier soils, such as clays, which do not erode as readily as silt or sand. Iowa, where the loess soil erodes readily, was one of the first States to submit lip curb on a Federal-aid project.

Type of Curb Used by Iowa in 1925. Note Berm Sloping Toward Pavement

The lip curb is constructed immediately after the pavement proper has been finished. The side forms are raised to the required elevation, and then the extra concrete of the same mix as the pavement is spread next to the form and finished to the proper cross section with a float. In Georgia the corner is rounded with an edging tool. Offtakes are constructed at suitable locations, the design of the opening varying with the steepness of the roadway grade.

In both Illinois and Georgia the unit for payment is the lineal foot of lip curb. On one project in Illinois the price was 10 cents, and on a job in Georgia the cost was 4 cents a lineal foot. In Minnesota and Iowa the cost is included in the unit price bid for the concrete pavement.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Pubiic Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463D. Earth, Sand-clay, and Gravel Roads. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
*1077D. Portland Cement Concrete Roads. 15c.
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

DEPARTMENT BULLETINS—Continued

No. 1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 94C. T. N. T. as a Blasting Explosive.
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal Aid Highway Projects.
93M. Direct Production Costs of Broken Stone.
*105M. Federal Legislation Providing for Federal Aid in Highway Construction and the Construction of National Forest Roads and Trails. 5c.

FARMERS' BULLETINS

No. *338F. Macadam Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *739Y. Federal Aid to Highways, 1917. 5c.
*849Y. Roads. 5c.
914Y. Highways and Highway Transportation.
937Y. Miscellaneous Agricultural Statistics.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Connecticut.
Report of a Survey of Transportation on the State Highway System of Ohio.
Report of a Survey of Transportation on the State Highways of Vermont.
Report of a Survey of Transportation on the State Highways of New Hampshire.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION AS OF JUNE 30, 1928

State	Completed Mileage	Under Construction: Estimated Total Cost	Under Construction: Federal Aid Allotted	Under Construction Mileage: Original	Under Construction Mileage: Stage [1]	Under Construction Mileage: Total	Approved for Construction: Estimated Total Cost	Approved for Construction: Federal Aid Allotted	Approved for Construction Mileage: Original	Approved for Construction Mileage: Stage [1]	Approved for Construction Mileage: Total	Balance of Federal Aid Funds Available for New Projects	State
Alabama	1,748.0	$ 5,195,635.95	$ 2,583,180.18	270.5	55.9	326.4	$ 717,945.71	$ 358,972.93	48.7	12.4	61.1	$ 1,645,844.81	Alabama
Arizona	851.4	1,795,361.35	1,577,922.94	86.0	0.6	86.6	122,094.33	42,024.80		4.2	4.2	2,896,024.65	Arizona
Arkansas	1,678.2	4,906,901.45	2,174,942.33	180.7		180.7	250,474.26	102,444.55	9.9	6.2	16.1	1,766,771.75	Arkansas
California	1,455.6	6,122,281.76	2,929,250.54	120.7	8.2	128.9	1,573,168.56	703,031.15	43.7		43.7	3,363,012.39	California
Colorado	979.3	5,134,698.11	2,627,641.63	189.4	9.2	198.5	287,928.34	159,230.93	12.7	14.5	27.2	2,573,202.04	Colorado
Connecticut	206.5	3,269,777.06	831,098.01	34.4		34.4	285,289.67	66,951.17	3.6		3.6	566,752.61	Connecticut
Delaware	195.7	470,022.22	95,739.75	5.7	3.9	9.6	310,591.60	155,295.80	12.9		12.9	190,680.44	Delaware
Florida	385.8	4,185,912.27	1,773,093.63	99.7	5.4	105.1	905,396.31	333,505.44	30.7		30.7	1,210,489.75	Florida
Georgia	2,457.5	3,701,359.50	1,805,098.52	168.2	30.7	198.9	2,934,550.18	1,239,573.27	102.3	50.1	152.4	17,567.82	Georgia
Idaho	937.1	2,067,804.47	1,235,873.81	116.5	56.8	173.3	1,100,504.72	653,836.57	101.6	1.8	103.4	138,890.41	Idaho
Illinois	1,685.4	19,966,945.33	9,204,790.58	620.1		620.1	3,896,721.88	1,942,068.60	148.0		148.0	114,597.22	Illinois
Indiana	1,060.1	10,285,596.57	4,915,301.36	314.2	3.5	317.7	1,671,729.13	807,135.04	61.3		61.3	267,083.14	Indiana
Iowa	2,831.5	7,006,259.73	2,993,700.52	145.2	137.3	282.5	1,827,757.31	778,011.52	10.2	71.4	81.6	171,307.77	Iowa
Kansas	2,202.4	4,812,182.97	1,907,366.82	242.8		242.8	1,348,337.76	598,232.45	106.3		106.3	1,284,552.84	Kansas
Kentucky	1,148.9	4,924,557.22	2,488,415.98	227.4		227.4	1,159,696.00	579,848.00	62.7		62.7	529,296.09	Kentucky
Louisiana	1,276.0	4,161,328.09	2,072,905.40	193.0		193.0	724,325.88	239,803.83	8.8		8.8	317,573.20	Louisiana
Maine	428.7	1,294,982.17	528,952.60	39.7		39.7	586,603.30	200,682.36	14.2		14.2	1,380,996.50	Maine
Maryland	557.5	738,690.77	353,730.00	30.0		30.0	858,534.80	416,900.00	38.6	7.2	45.8	143,816.23	Maryland
Massachusetts	501.1	3,785,205.01	1,133,667.82	71.4		71.4	361,296.54	84,345.00	5.6		5.6	2,151,419.10	Massachusetts
Michigan	1,337.3	13,340,940.37	5,616,223.08	328.5		328.5	1,150,043.70	525,885.00	29.4	6.5	35.9	627,344.95	Michigan
Minnesota	3,823.8	6,287,137.06	2,088,100.00	305.9	54.7	360.6	1,201,168.05	291,000.00	49.8	20.6	70.4	398,471.43	Minnesota
Mississippi	1,533.6	4,361,785.79	2,149,654.95	228.3	30.9	259.2	201,358.23	100,459.53	11.5	0.6	12.1	892,222.08	Mississippi
Missouri	2,210.1	4,630,264.01	1,900,212.49	132.8	39.0	171.8	1,511,404.60	602,718.59	46.3	13.7	60.0	1,550,939.55	Missouri
Montana	1,299.3	3,526,790.69	2,385,241.58	275.6	4.1	279.7	2,345,539.14	1,308,589.18	235.1	10.7	245.8	4,353,988.31	Montana
Nebraska	3,032.3	6,436,612.14	3,206,959.06	644.1	197.4	841.5	75,620.57	37,768.83		23.2	23.2	1,999,143.13	Nebraska
Nevada	1,018.6	1,156,011.48	1,012,597.47	137.3	28.4	165.7	59,079.34	51,419.58		23.7	23.7	595,556.89	Nevada
New Hampshire	305.6	681,935.44	272,455.16	19.0		19.0	490,414.66	190,235.78	9.2		9.2	65,727.25	New Hampshire
New Jersey	419.3	5,847,748.19	1,039,947.35	71.3		71.3						253,177.00	New Jersey
New Mexico	1,740.3	2,414,979.86	1,602,034.50	155.2		155.2	777,265.15	492,343.74	56.1	0.5	56.6	894,813.28	New Mexico
New York	1,864.8	30,549,500.00	7,134,693.95	460.6		460.6	8,328,900.00	1,806,847.50	116.9	8.6	125.5	3,910,462.81	New York
North Carolina	1,582.4	2,052,044.50	981,951.81	89.7	13.0	102.7	534,495.97	259,500.00	5.0	19.5	24.5	1,141,531.23	North Carolina
North Dakota	3,155.1	3,660,655.06	1,740,332.78	626.3	165.4	791.7	1,240,836.16	502,502.23	192.4	121.7	314.1	637,992.37	North Dakota
Ohio	1,805.9	11,260,370.37	4,150,846.38	250.2	6.0	256.2	4,757,780.00	1,340,636.26	88.6	6.7	95.3	2,591,001.85	Ohio
Oklahoma	1,589.7	3,367,788.78	1,617,074.66	171.0	6.4	177.4	1,871,838.77	837,936.01	109.7	15.5	125.2	387,602.49	Oklahoma
Oregon	1,104.9	1,517,571.16	847,554.19	40.7		40.7	278,334.10	146,673.72	6.7		6.7	1,267,098.47	Oregon
Pennsylvania	1,837.0	13,745,519.18	3,983,882.84	240.7		240.7	4,414,639.79	1,318,026.22	82.4		82.4	1,850,129.27	Pennsylvania
Rhode Island	136.2	1,723,452.42	431,049.92	26.8		26.8	311,081.95	80,919.55	4.0		4.0	576,046.16	Rhode Island
South Carolina	1,631.6	8,499,229.16	1,887,138.22	205.5	120.7	326.2	394,006.44	69,700.00	10.4	8.1	18.5	64,396.43	South Carolina
South Dakota	2,834.4	3,458,251.40	1,855,200.66	584.0	73.3	657.3	655,789.73	360,684.24	107.0	39.2	146.2	514,514.16	South Dakota
Tennessee	1,075.6	4,524,754.78	1,939,405.06	138.9		138.9	4,267,517.00	1,368,324.58	25.6	94.3	119.9	254,777.15	Tennessee
Texas	5,985.9	8,914,648.60	3,494,782.06	224.8	125.1	349.9	6,241,573.47	2,627,108.00	161.9	156.0	317.9	3,975,468.70	Texas
Utah	806.5	1,996,561.57	1,364,094.82	112.2	12.3	124.5	328,886.36	240,095.90	19.4	1.5	20.9	220,749.79	Utah
Vermont	201.3	2,345,384.25	584,978.39	51.2		51.2	584,323.08	147,454.36	11.9		11.9	25,473.81	Vermont
Virginia	1,266.9	4,221,703.93	1,337,952.75	99.3	21.6	120.9	884,718.69	156,605.91	31.6		31.6	237,853.61	Virginia
Washington	777.7	4,144,458.77	1,437,000.00	105.4	18.1	123.5	1,142,840.68	440,236.89	21.2	5.0	26.2	481,843.46	Washington
West Virginia	606.9	2,789,397.94	1,244,328.22	105.6		105.6	617,098.44	294,283.84	25.3		25.3	478,768.16	West Virginia
Wisconsin	2,046.9	7,931,130.44	3,251,570.37	277.2	25.2	302.4	1,400,034.42	433,988.43	36.5	15.7	52.2	1,435,440.82	Wisconsin
Wyoming	1,442.5	2,260,697.90	1,417,612.15	227.0	32.1	259.1	296,051.33	190,064.91	41.8		41.8	167,116.50	Wyoming
Hawaii	36.2	301,973.75	60,383.43	3.2		3.2	175,931.99	57,501.20	1.8		1.8	1,064,241.58	Hawaii
Totals	71,074.3	261,754,800.99	105,297,930.62	9,493.9	1,285.2	10,779.0	67,461,518.09	25,741,403.29	2,359.3	759.1	3,118.4	53,643,770.45	Totals

1. The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of surface of higher type than was provided in the original improvement.